Advances in Aquaculture

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Edited by

T. V. R. Pillay
Fisheries Department
FAO, Rome, Italy

and

Wm. A. Dill
730 North Campus Way, Davis
California, U.S.A.



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List of Contributors

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ALLEN, G. H. 478, 492
Fisheries Department, School of Natural Resources, Humboldt State University, Arcata, California, U.S.A.

ALLISON, R. 168
Department of Fisheries and Allied Aquacultures, Auburn University, Agricultural Experiment Station, Auburn, Alabama, U.S.A.

ARAI, S. 584
Freshwater Fisheries Research Laboratory, Fisheries Agency, Ministry of Agriculture and Forestry, Hino, Tokyo, Japan

ARMIJO ORTIZ, A. 149
Instituto Nacional de Pesca, México DF, México

AQUACOP 590
Centre Océanologique du Pacifique, Vairao, Tahiti, Polynésie Française

ASANO, I. 74
Research and Development Department, Fishery Agency, Hino, Japan

BAKOS, J. 633
Fish Culture Research Institute, Szarvas, Hungary

BAUR, R. J. 489
Illinois Natural History Survey, Kinmundy, Illinois, U.S.A.

BECK, H. 596
Institut für Physiologie, Physiologische Chemie und Ernährungsphysiologie im Fachbereich Tiermedizin der Universität München, Federal Republic of Germany

BERGE, L. 239
5630 Strandebarm, Norway

BISHOP, F. J. 580
Environment Canada, Fisheries and Marine Service, Halifax Laboratory, Halifax, Nova Scotia, Canada

BOLTON, E. T. 525
College of Marine Studies, University of Delaware, Lewes, Delaware, U.S.A.

BOSCH, A. 339
Centro de Investigaciones Pesqueras, Instituto Nacional de la Pesca, La Habana, Cuba

BOSCHI, E. E. 268
Instituto de Biologia Marina, Mar del Plata, Argentina

BOYD, C. E. 120
Department of Fisheries and Allied Aquacultures, Auburn University, Agricultural Experiment Station, Auburn, Alabama, U.S.A.

BRIGGS, P. 40
The Commercial Fish Farmer, Little Rock, Arkansas, U.S.A.

BRODY, T. 635
Department of Genetics, The Hebrew University of Jerusalem, Jerusalem, Israel

BROWN, E. E. 235
Agricultural Economics Department, University of Georgia, Athens, Georgia, U.S.A.

Page No.

BUCK, D. H. 489
Illinois Natural History Survey, Kinmundy, Illinois, U.S.A.

BUSCH, R. A. 492
Fisheries Department, School of Natural Resources, Humboldt State University, Arcata, California, U.S.A.

BUYÜKHATIPOGLU, S. 141
Institut für Tierzucht und Haustiergenetik der Universität Göttingen, Göttingen, Federal Republic of Germany

CABRERO, J. 168
Department of Fisheries and Allied Aquacultures, Auburn University, Agricultural Experiment Station, Auburn, U.S.A.

CARRIKER, M. R. 525
College of Marine Studies, University of Delaware, Lewes, Delaware, U.S.A.

CASTAGNOLLI, N. 180
Faculdade de Medicina Veterinária e Agronomia de Jaboticabal, São Paulo State, Brazil

CASTELL, J. D. 314
Environment Canada, Fisheries and Marine Service, Halifax Laboratory, Halifax, Nova Scotia, Canada

CASTELL, J. R. 410
Marine Colloids, Inc, Rockland, Maine, U.S.A.

CAUBET, J. L. 277
C A T, Palavas les Flots, France

CHAKRABARTY, R. D. 153
Central Inland Fisheries Research Substation, Cuttack, India

CHATTERJEE, D. K. 134
Central Inland Fisheries Research Substation, Cuttack, India

CHAUDHURI, H. 127
Central Inland Fisheries Research Substation, Cuttack, India

COCHE, A. G. 428
Department of Fisheries, FAO, Rome, Italy

COLLINS, R. A. 472
University of Central Arkansas, Conway, Arkansas, U.S.A.

CONROY, D. A. 201
FAO/UNDP Inland Water Fisheries Development Project, Bogota, DE, Colombia

CORLISS, J. 592
National Marine Fisheries Service, Gulf Coastal Fisheries Center, Galveston, Texas, U.S.A.

COSTELLO, T. J. 299
NOAA National Marine Fisheries Service, Southeast Fisheries Center, Miami, Florida, U.S.A.

CRACKNELL, T. J. 34
Shearwater Fish Farming Limited, U.K

DELMENDO, M. N. 472
Department of Fisheries, FAO, Rome, Italy

Page No.

DEVEAU, L. E. 410
Marine Colloids, Inc. Rockland, Maine, U.S.A.

DILLON, O. W. JR 50
Soil Conservation Service, Fort Worth, Texas, U.S.A.

EDWARDS, R. D. 466
White Fish Authority, Marine Farming Unit, Ardtoe, Acharacle, Argyll, Scotland

EPIFANIO, C. E. 525
College of Marine Studies, University of Delaware, Lewes, Delaware, U.S.A.

FACTOROVICH, K. A. 628
State Research Institute of Lake and River Fisheries, Leningrad, U.S.S.R.

FARWELL, M. K. 560
Department of the Environment, Fisheries and Marine Services, St John's, Newfoundland, Canada

FINUCCI, J. L. 601
Gulf Fisheries Center, National Marine Fisheries Service, Galveston, Texas, U.S.A.

FIGUERAS, A. 361
Instituto de Investigaciones Pesqueras, Vigo, Spain

FUJIYA, M. 453
Freshwater Fisheries Research Laboratory, Hino-shi, Tokyo, Japan

FURFARI, S. A. 385
Shellfish Sanitation Branch, Food and Drug Administration, Washington, DC, U.S.A.

FURUKAWA, A. 45
Japan Sea Regional Fisheries Research Laboratory, Niigata, Japan

GERHARDSEN, G. M. 10
Institute of Fisheries Economics, The Norwegian School of Economics and Business Administration, Norway

GHITTINO, P. 92
International Office of Epizootics (OIE), Fish Disease Laboratory, Turin, Italy

GHOSH, S. R. 153
Central Inland Fisheries Research Substation, Cuttack, India

GIRIN, M. 173
Centre Océanologique de Bretagne, Brest, France

GLUDE, J. B. 325
National Marine Fisheries Service, Seattle, Washington, U.S.A.

GOPALAKRISHNAN, V. 58
FAO/UNDP Aquaculture Project, Tarawa, Gilbert & Ellice Islands

GREEN, O. L. 626
Southeastern Fish Cultural Laboratory, U.S. Fish and Wildlife Service, Marion, Alabama, U.S.A.

GROPP, J. 596
Institut für Physiologie, Physiologische Chemie und Ernährungsphysiologie im Fachbereich Tiermedizin der Universität München, Federal Republic of Germany

Page No.

GROVER, JOHN H. 223
Freshwater Aquaculture Center, Central Luzon State University, Muñoz, Nueva Ecija, Philippines

GUERRERO, L. A. 305
Freshwater Aquaculture Center, Central Luzon State University, Muñoz, Nueva Ecija, Philippines

GUERRERO, R. D. III 166, 305
Freshwater Aquaculture Center, Central Luzon State University, Muñoz, Nueva Ecija, Philippines

HALVER, J. E. 574
U.S. Fish and Wildlife Service, College of Fisheries, University of Washington, Seattle, Washington, U.S.A.

HAMLISCH, R. 77
Department of Fisheries, FAO, Rome, Italy

HANAMURA, N. 541
Nansei Regional Fisheries Research Laboratory, Hiroshima, Japan

HARACHE, Y. 173
Centre Océanologique de Bretagne, Brest, France

HASTINGS, W. H. 568
Sedro Woolley, Washington, U.S.A.

HEPHER, B. 478, 487
Fish and Aquaculture Research Station, Dor, Israel

HILGE, V. 505
Institut für Küsten und Binnenfischerei der Bundesforschungsanstalt für Fischerei, Ahrensburg, Federal Republic of Germany

HILL, T. K. 523
Department of Entomology and Fisheries, Coastal Plain Experiment Station, Tifton, Georgia, U.S.A.

HIRASAWA, Y. 288
Tokyo University of Fisheries, Minato-Ku, Tokyo, Japan

HOLM, M. 622
Institute of Marine Research, Directorate of Fisheries, Bergen, Norway

HOLTZ, W. 141
Institut für Tierzucht und Haustiergenetik der Universität Göttingen, Göttingen, Federal Republic of Germany

HOMMA, A. 197
Department of Research and Development, Fisheries Agency, Kasumigaseki, Chiyoda-ku, Tokyo, Japan

HUTATA, G. 635
Fish and Aquaculture Research Station, Dor, Israel

HULL, S. T. 466
White Fish Authority, Marine Farming Unit, Ardtoe, Acharacle, Argyll, Scotland

ILYASOV, YU. I. 628
All-Union Research Institute of Pond Fisheries, Dmitrov, U.S.S.R.

ISHIDA, R. 563
Freshwater Fisheries Research Laboratory, Fisheries Agency, Tokyo, Japan

Page No.

JHINGRAN, V. G. 532
Central Inland Fisheries Research Institute, Barrackpore, West Bengal, India

KAMARA, A. B. 344
Fisheries Division, Ministry of Agriculture & Natural Resources, Freetown, Sierra Leone

KATO, J. 458
National Research Institute of Agricultural Engineering, Japan

KAWAGUCHI, K. 197
Department of Research and Development, Fisheries Agency, Kasumigaseki, Chiyoda ku, Tokyo, Japan

KAWATSU, H. 197
Freshwater Fisheries Research Laboratory, Fisheries Agency, Hinoshi, Tokyo, Japan

KIRPICHNIKOV, V. S. 628
Institute of Cytology, U.S.S.R Academy of Science, Leningrad, U.S.S.R.

KOBAYASHI, T. 554
Hokkaido Salmon Hatchery, Hokkaido Prefecture, Japan

KOGANEZAWA, A. 332
Japan Sea Regional Fisheries Research Laboratory, Niigata, Japan

KOOPS, H. 596
Institut für Küsten- und Binnenfischerei der Bundesforschungsanstalt für Fischerei, Hamburg, Federal Republic of Germany

KORRINGA, P. 371
Netherlands Institute for Fishery Investigations, Ijmuiden, Netherlands

KUHLMANN, H. 502
Institut für Küsten- und Binnenfischerei der Bundesforschungsanstalt für Fischerei, Hamburg, Federal Republic of Germany

KURATA, H. 258
Nansei Regional Fisheries Research Laboratory, Ohnocho, Hiroshima, Japan

LAFON, R. 277
C A T, Palavas les Flots, France

LALL, S. P. 580
Environment Canada, Fisheries and Marine Service, Halifax Laboratory, Halifax, Nova Scotia, Canada

LANGHOLZ, H. J. 141
Institut für Tierzucht und Haustiergenetik der Universität Göttingen, Göttingen, Federal Republic of Germany

LAUBIER, L. 273
Centre Océanologique de Bretagne, Brest, France

LAUBIER-BONICHON, A. 273
Centre Océanologique de Bretagne, Brest, France

LERØY, R. 622
Institute of Marine Research, Directorate of Fisheries, Bergen, Norway

LINDBERGH, J. M. 441
Dømsea Farms Inc., Bremerton, Washington, U.S.A

Page No.

LING, S. W. 299
University of Miami, School of Marine and Atmospheric Science, Miami, Florida, U.S.A.

LOVELL, R. T. 186, 605
Department of Fisheries and Allied Aquacultures, Auburn University, Auburn, Alabama, U.S.A.

MCNEIL, K. B. 344
Industrial Development Research Centre (IDRC), Freetown, Sierra Leone

MCNEIL, W. J. 547
National Marine Fisheries Service, Northwest Fisheries Center, Auke Bay, Alaska, U.S.A.

MACFARLANE, I. S. 70, 90
Fish Farm Development Ltd., Ardrishaig, Argyll, Scotland

MACHADO, C. R. 180
Faculdade de Medicina Veterinária e Agronomia de Jaboticabal, São Paulo State, Brazil

MASSE, J. 170
Ministère de l'Agriculture, CTGREF, Bordeaux, France

MAY, R. C 184
Hawaii Institute of Marine Biology, Kaneohe, Hawaii, U.S.A.

MAYO, R. D. 508
Kramer, Chin and Mayo, Inc., Seattle, Washington, U.S.A

MEIXNER, R. 338
Institut für Küsten- und Binnenfischerei der Bundesforschungsanstalt für Fischerei, Hamburg, Federal Republic of Germany

MESKE, CH. 527
Bundesforschungsanstalt für Fischerei, Ahrensburg/Holst, Federal Republic of Germany

MILNE, P. H. 416
Department of Civil Engineering, University of Strathclyde, Glasgow, Scotland

MIZUMOTO, S. 381
National Pearl Research Laboratory, Kashikojima, Mie Prefecture,

MOAV, R. 610, 635
Institute of Animal Science, Agricultural Research Organization, The Vulcani Center, Bet Dagan, Israel

MOCK, C. R. 521
National Marine Fisheries Service, Gulf Coastal Fisheries Center, Galveston, Texas, U S.A

MOLLER, D. 447, 622
Institute of Marine Research, Directorate of Fisheries, Bergen, Norway

MORTON, A. W. 492
Fisheries Department, School of Natural Resources, Humboldt State University, Arcata, California, U.S.A.

NAEVDAL, G. 622
Institute of Marine Resources, Directorate of Fisheries, Bergen, Norway

Page No.

NAIDU, K. S. 379
Environment Canada, Fisheries and Marine Service, Newfoundland Biological Station, St John's, Newfoundland, Canada

NAKANISHI, T. 319
Hokkaido Regional Fisheries Research Laboratory, Yoichi, Hokkaido, Japan

NATARAJAN, A. V. 532
Central Inland Fisheries Research Institute, Barrackpore, West Bengal, India

NEAL, R. A. 270, 521
National Marine Fisheries Service, Gulf Coastal Fisheries Center, Galveston, Texas, U.S.A.

NEISH, I. C. 395
Applied Marine Research Limited, Halifax, Nova Scotia, Canada

NIKOLIĆ, M. 339
Centro de Investigaciones Pesqueras, Instituto Nacional de la Pesca, La Habana, Cuba

NOMA, T. 458
National Research Institute of Agricultural Engineering, Japan

NOSE, T. 584
Freshwater Research Laboratory, Fisheries Agency, Ministry of Agriculture and Forestry, Hino, Tokyo, Japan

OLDIGS, B. 141
Institut für Tierzucht und Haustiergenetik der Universität Göttingen, Göttingen, Federal Republic of Germany

OLIVA SUÁREZ, M. 284
Centro de Investigaciones Marinas, Universidad de La Habana, La Habana, Cuba

PANTULU, V. R. 53, 423
Mekong Secretariat, ESCAP of the United Nations, Sala Santitham, Bangkok, Thailand

PARDUE, G. B. 626
U.S. Fish and Wildlife Service, Washington, DC, U.S.A.

PÉREZ PÉREZ, D. 284
Centro de Investigaciones Marinas, Universidad de La Habana, La Habana, Cuba

PERROT, J. 247
Centre National pour l'Exploitation des Océans, Paris, France

PILLAY, T. V. R. 1, 84
Department of Fisheries, FAO, Rome, Italy

PORTER, T. R. 560
Department of the Environment, Fisheries and Marine Services, St John's, Newfoundland, Canada

PRICE, K. S. 525
College of Marine Studies, University of Delaware, Lewes, Delaware, U.S.A.

PRUDER, G. D. 525
College of Marine Studies, University of Delaware, Lewes, Delaware, U.S.A.

QUAYLE, D. B. 344
Nanaimo, British Colombia, Canada

Page No.

RABANAL, H. R. 224
FAO/UNDP South China Sea Fisheries Development and Coordinating Programme, Manila, Philippines

RAMÍREZ GRANADOS, R. 23
Instituto Mexicano de Comercio Exterior, México DF, México

RAO, N. G. S. 153
Central Inland Fisheries Research Substation, Cuttack, India

RENÉ, F. 277
C A T, Palavas les Flots, France

RIORDAN, P. F. 27
Groton Bioindustries Development Company, Groton, Massachusetts, U.S.A.

ROSE, C. R. 489
Illinois Natural History Survey, Kinmundy, Illinois, U.S.A.

SAITO, Y. 402
Aquaculture Research Division, Nansei Regional Fisheries Research Laboratory, Ohno-cho, Saeki-gun, Hiroshima ken, Japan

SALES, C. 277
C A T, Palavas les Flots, France

SÁNCHEZ, C. 311
Servicio de Recursos Pesqueros, Ministerio de Agricultura y Ganadería, San Salvador, El Salvador

SANDIFER, P. A. 306
Marine Resources Research Institute, Charleston, South Carolina, U.S.A.

SARIG, S. 190
Laboratory for Research of Fish Diseases, Nir-David, Israel

SASSO YADA, L. 149
Instituto Nacional de Pesca, México DF, México

SCAPLEN, R. 379
Marine Sciences Research Laboratory, Memorial University of Newfoundland, St John's, Newfoundland, Canada

SCILZO, M. A. 268
Instituto de Biologia Marina, Mar del Plata, Argentina

SCHROEDER, G. 487
Fish and Aquaculture Research Station, Dor, Israel

SECRETAN, P. A. D. 63
The Aquacultural Insurance Service Ltd., London, England

SEN, P. R. 134, 153
Central Inland Fisheries Research Substation, Cuttack, India

SHANG, Y. C. 224
Hawaii Institute of Marine Biology, University of Hawaii at Manoa, Kaneohe, Hawaii, U.S.A.

SHART, L. A. 628
All-Union Research Institute of Pond Fisheries, Dmitrov, U.S.S.R.

SHIGUENO, K. 258
Kagoshima Fisheries Research Station, Kinkocho, Kagoshima, Japan

Page No

SINDERMANN, C. J. 349
National Marine Fisheries Service, U S Department of Commerce, Highlands, New Jersey, U.S.A.

SINHA, V. R. P. 123
Central Inland Fisheries Research Institute, Barrackpore, West Bengal, India

SMITH, K. P. 525
College of Marine Studies, University of Delaware, Lewes, Delaware, U.S.A.

SMITH, P. L. 143
White Fish Authority, Marine Farming Unit, Ardtoe, Acharacle, Argyll, Scotland

SMITH, T. I. J. 306
Marine Resources Research Institute, Charleston, South Carolina, U.S.A.

SMITHERMAN, R. O. 168, 626
Department of Fisheries and Allied Aquacultures, Auburn University, Agricultural Experiment Station, Auburn, U.S.A.

SORGELOOS, P. 321
State University of Ghent, Ghent, Belgium

SRNA, R. F. 525
College of Marine Studies, University of Delaware, Lewes, Delaware, U.S.A.

STEWART, J. E. 314
Environment Canada, Fisheries and Marine Service, Halifax Laboratory, Halifax, Nova Scotia, Canada

STOSS, J. 141
Institut für Tierzucht und Haustiergenetik der Universitat Gottingen, Gottingen, Federal Republic of Germany

SUZUKI, R. 161
Ueda Branch Station, Freshwater Fisheries Research Laboratory, Komaki, Ueda, Nagano Prefecture, Japan

SZUMIEC, J. 157
Polish Academy of Sciences, Experimental Fish Culture Station at Golysz, Poland

SZUMIEC, M. A. 117
Polish Academy of Sciences, Experimental Fish Culture Station at Golysz, Poland

Page No

TANAKA, J. 499
Tokai Regional Fisheries Research Laboratory, Arazaki, Nagai, Yokosuka, Japan

TANG, Y. A. 99, 104
Department of Fisheries, FAO, Rome, Italy

TIEWS, K. 596
Institut für Küsten und Binnenfischerei der Bundesforschungsanstalt für Fischerei, Hamburg, Federal Republic of Germany

TRIPATHI, S. D. 127
Central Inland Fisheries Research Institute, Barrackpore, India

UEKITA, Y. 458
National Research Institute of Agricultural Engineering, Japan

VARLEY, R. L. 70
Department of Industrial Science, University of Stirling, Scotland

VÁSQUEZ D., C. 201
FAO/UNDP Inland Water Fisheries Development Project, Bogotá, DE, Colombia

VÁZQUEZ, B. 339
Centro de Investigaciones Pesqueras, Instituto Nacional de la Pesca, La Habana, Cuba

VINCKE, M. M. J. 208
Project FAO/UNDP Vulgarisation de la Pisciculture, Bangui Landjia, Africa

WALFORD, J. 288
Tokyo University of Fisheries, Minato-Ku, Tokyo, Japan

WEBBER, H. H. 27
Groton Biomdustries Development Company, Groton, Massachusetts, U.S.A.

WOHLFARTH, G. 635
Fish and Aquaculture Research Station, Dor, Israel

WOYNAROVICH, F. 203
FAO/UNDP Fishery and Fish Culture Development Project, Caracas, Venezuela

ZEIN-ELDIN, Z. P. 592, 601
National Marine Fisheries Service, Gulf Coastal Fisheries Center, Galveston, Texas, U S A

Foreword

It is my great pleasure to introduce this important publication. The book contains most of the papers presented at the FAO Technical Conference on Aquaculture held in Tokyo, Japan, 26 May–2 June 1976. It should be read in conjunction with the report of the Conference itself (FAO Fisheries Report No. 188, 1976) which contains a number of recommendations based on discussion of these papers. Together they constitute a comprehensive review of recent technical developments as well as an analysis of potentials and problems in this field of food production.

The total yield from wild stocks of marine species of familiar types is still increasing, but at a progressively reduced rate. While the Law of the Sea Conference has not produced a worldwide agreement, the new regime of the sea based on the concept of exclusive economic zones is a reality as far as fisheries are concerned. Thus, the world is now facing problems of realigning marine fishing activities. Growing attention is being paid to aquaculture as a means to increase further the production of aquatic food, particularly animal protein food.

To many countries aquaculture is something of a novelty. To others it consists of traditional practices, some of which have a history of many centuries. Some people view aquaculture as a way to make further contributions to the supply of animal protein food, while others consider it as a means to raise high-priced aquatic species for profit. Technically, aquaculture means many different things, ranging from modest improvements in the environment in which aquatic animals live, through extensive forms of fish farming, to highly sophisticated systems of intensive culture. A great variety of animals and plants are raised. While some forms of aquaculture can almost be called industrial enterprises, small scale fish farming in rural areas is of special importance to villagers and farmers.

Most of the recommendations of the Conference contained in the report are addressed to governments, suggesting ways and means to expand aquaculture production by removing technical, economic and social constraints and providing incentives for increased input. In summary, this book and the Conference report together show what aquaculture is and what technical and other factors are involved in expanding various systems of culture and increasing their production.

The Conference was attended by some 600 people and about 120 papers were contributed. It was the largest fishery conference ever organized by FAO. Financially, it was made possible by the generous offer of the Government of Japan to host it and additional contributions from the United Nations Development Programme, and the Governments of Canada and the United States of America. I wish to close these remarks by expressing my sincere appreciation to all the people who made a great effort to make this undertaking successful, including the secretariat of the Conference, the authors of papers, those who served as session conveners, the editors and the publisher.

K. C. Lucas
Assistant Director-General (Fisheries)

Preface

Technical conferences and symposia are often of crucial importance in the development of scientific disciplines; they assume special significance in international efforts to identify potentials, problems and requirements. Some of the world conferences organized by FAO have played very important roles in the promotion of research and development in the field of fisheries. The World Symposium on Warm Water Pond Fish Culture held in Rome (Italy) in May 1966 can be cited as a good example, as it was a turning point in FAO's activities related to aquaculture. The majority of its recommendations were implemented in one way or the other, laying the foundations for regional and international cooperation for the development of the sector. One of its recommendations was that a similar symposium should be held in five years' time 'to review the major changes, trends and innovations which may have occurred in this period'. Some of the fishery meetings held since also strongly endorsed this recommendation. However, it was felt that the next world meeting in this field should attempt to cover the whole field of aquaculture, which obviously meant much more preparation and effort than conceived by the symposium. It was therefore decided that a world conference on aquaculture should be prepared for, through a series of regional symposia under the auspices of FAO regional fishery bodies. On the completion of six such regional meetings, held from 1970 to 1975, the FAO Technical Conference on Aquaculture was organized in Kyoto, Japan, 26 May 2 June 1976, with the main objectives of synthesizing on a global basis the experience so far gained in the development of aquaculture, including natural resources improvement; reviewing the state of the technology related to the different aquaculture systems in order to identify areas in which research and developmental efforts should be concentrated in the future; and to formulate a strategy for rapid expansion and intensification of the industry with due consideration of the relevant social, legal and economic factors and infrastructure requirements.

This Conference was in many ways a landmark in the field of aquaculture. It served to bring together in one forum a broad spectrum of scientists, technicians, administrators, entrepreneurs and financiers, representing government, academic and private institutions. A total of 17 technical sessions including five special sessions were held to discuss the following main topics:

(*1*) State of world aquaculture and its future role
(*2*) Pond culture of finfish
(*3*) Culture of crustaceans
(*4*) Culture of molluscs
(*5*) Oyster mortalities and their control
(*6*) International aspects of disease control in aquaculture
(*7*) Culture of algae and sea weeds
(*8*) Integration of aquaculture with agriculture and animal production
(*9*) Aquaculture in raceways, cages and enclosures
(*10*) Aquaculture in recirculating water and recycling of wastes in aquaculture
(*11*) Nutritional requirements of cultivated organisms and feed technology
(*12*) Genetics and genetic improvement in aquaculture
(*13*) Artificial recruitment and transplantation
(*14*) Legal, social and economic aspects of aquaculture
(*15*) Problems of vertically integrated aquaculture industries
(*16*) Strategy for future aquaculture development
(*17*) Main conclusions and recommendations.

An overview of developments in the field of aquaculture during the last decade revealed that there has been an overall increase of about 20% in world aquaculture production since 1975, and the really significant increases have been in countries where sufficient importance was given to the industry in national agricultural and industrial development programmes, leading to increased government spending, enhanced private capital investment and better support services. The lack of public understanding is one of the main constraints on creative policy development leading to well established aquaculture industries. The Conference therefore adopted the following statement that has come to be known as the 'Kyoto Declaration on Aquaculture'.

Kyoto Declaration on Aquaculture

The FAO Technical Conference on Aquaculture, assembled in Kyoto, Japan, on 2 June 1976, after a week-long review of present state, problems, opportunities and potential for the culture of fish, crustaceans, molluscs and seaweeds, declares:

(*1*) That aquaculture has made encouraging progress in the past decade, producing significant quantities of food, income and employment; that realistic estimates place future yields of food at twice the present level in ten years, and five times the present level in 30 years if adequate support is provided.
(*2*) That aquaculture, imaginatively planned and intelligently applied, provides a means of revitalizing rural life and of supplying products of high nutritional value, and that aquaculture, in its various forms, can be practised in most countries, coastal and land locked, developed and developing.
(*3*) That aquaculture has a unique potential contribution to make to the enhancement and maintenance of wild aquatic stocks and thereby to the improvement of capture fisheries, both commercial and recreational.
(*4*) That aquaculture forms an efficient means of recycling and upgrading low grade food materials and waste products into high-grade protein rich food.
(*5*) That aquaculture can, in many circumstances, be combined with agriculture and animal husbandry with mutual advantage, and contribute substantially to integrated rural development.
(*6*) That aquaculture provides intellectual challenge to skilled professionals of many disciplines, and a rewarding activity for farmers and other workers at many levels of skill and education.
(*7*) That aquaculture provides now, and will continue to provide, options for sound investment of money, materials, labour and skills.
(*8*) That aquaculture merits the fullest possible support and attention by national authorities for integration

into comprehensive renewable resource, energy, land and water use policies and programmes, and for ensuring that the natural resources on which it is based are enhanced and not impaired.

(9) That aquaculture could benefit greatly from support and assistance from international agencies, which should include the transfer of technology actively planned and executed, with research carried out in centres representative of various regions concerned.

The world production through aquaculture in 1975 was estimated to be over 6 million tons. The general trend today is toward intensive farming to achieve higher production per unit area and higher profit on investment, although extensive farming techniques, yielding relatively low production, are still feasible and economical in many developing countries.

The main strategy for further expansion proposed by the Conference laid stress on wider application of known technology and scientific information so as to attract much-needed investment in this sector. There are a number of proven systems of culture that can be used for expanding production through horizontal or vertical transfer of technology and governments and private sector agencies were urged to promote aquaculture production programmes. Financing agencies, particularly development banks, have a crucial role in the expansion of aquaculture production in developing countries. A large amount of basic information on new systems of culture has been accumulated through research during the last decade and its application in commercial production is hampered by the lack of suitable pilot-scale projects to test their technical and economic viability. The Conference therefore recommended that governments and financing agencies should support the establishment and operation of pilot-scale or model projects as required. As aquaculture, particularly small-scale fish farming, can have a major role in integrated rural development, it was suggested that governments should give appropriate consideration to the inclusion of aquaculture as an integral part of rural development plans, wherever possible. As the success of aquaculture production programmes depends, to a large extent, on the availability of essential inputs, such as seed, feed and fertilizers, high priority needs to be given to the production and distribution of these.

Aquaculture research, extension services and the training of core personnel for development work were other subjects that received the special attention of the Conference. It was recognized that a sound production programme based on transfer of existing technology and the development of new technologies would need systems-oriented multidisciplinary research at the appropriate level. The present state of techniques for the culture of finfish, crustaceans, molluscs, algae and sea weeds and of the different aquaculture production systems in use, were discussed by the Conference with special reference to the gaps in our knowledge and requirements of research to solve the problems faced by the industry. The Conference strongly recommended the establishment of regional networks of research centres for undertaking applied research at the appropriate level. The research centres could also provide adequate facilities for training of senior-level aquaculturists or aquaculture producers. Some of the legal problems related to aquaculture development received special attention and it was noted that the absence of a legal basis for the industry is a major constraint in many countries. Governments were therefore urged to enact appropriate aquaculture legislation, facilitating the establishment or expansion of the industry as needed and enabling the grant of financial and other incentives generally given to emerging industries, including the provision of risk guarantees.

A full report of the Conference, including the details of the discussions in various sessions, has been issued separately in the FAO Fisheries Report series (FAO Technical Conference on Aquaculture, Kyoto, Japan, 26 May–2 June 1976 (1976), *FAO Fish. Rep.*, (188):93 p.).

This volume contains the technical papers that formed the basis of discussions in the sessions and together constitute a general account of the advances in aquaculture technology and its application during the last decade. A number of colleagues have assisted in the editing of the manuscripts and the correction of proofs. Mr. T. G. Carey helped in the pre-Conference editing of the papers. Dr. A. G. Coche and Mr. J. Chaux helped with the editing of French texts and Dr. F. A. Pagán Font of Spanish texts. Mr. M. M. J. Vincke and Mr. M. Pedini corrected the French and Spanish proofs. Miss Gloria Soave was responsible for checking references and Mrs. Ann Bailey-de Wouytch gave invaluable help in many ways in all stages of production of this book. Grateful thanks are due to all of them and to Mr. A. R. Margetts for proof correction and preparation of the indices.

October, 1978
Rome, Italy

T. V. R. Pillay

Chapter I World Aquaculture and its Future Role

The State of Aquaculture 1976

T. V. R. Pillay

Abstract

This paper attempts an overview of the progress made in the field of aquaculture during the last decade and the problems now faced by the industry

Based on available information, world production through aquaculture in 1975 is estimated to be over 6 million tons During the last decade there has been a steady increase in aquaculture production. In most countries the trend has been toward the development of intensive or semi intensive culture systems.

Implementation of the ten year aquaculture development plans prepared by 34 developing countries in Africa, Asia and Latin America, and the production increases occurring in other countries, are expected to result in a total production of 12 million tons by the end of 1985 A number of factors such as the increased cost of fishing, expected changes in the laws of the sea and the need for relocating and finding employment for excess fishermen and under-employed farmers have served to focus renewed attention on aquaculture. On the other hand increases in the cost of feeds, shortage of fertilizers, aquatic pollution and in some cases indiscriminate application of certain environmental protection regulations, have hampered the expansion of the industry

There have been a number of technological advances in aquaculture during the last decade, the more important of which relate to the improvement and modernisation of traditional practices like cage and enclosure/pen culture of fish, polyculture, tilapia culture, shrimp and prawn farming, eel and oyster culture and recycling wastes through aquaculture including the use of waste heat The development of catfish farming in the USA is probably a good example of technology trying to keep up with rapid expansion of production requirements Reconditioning and reuse of water in hatcheries has become common in some countries. With improvements in the methods employed and demonstration of economic viability of the operations 'sea ranching' or 'aqua-range farming' has become an accepted technology. Two areas of research that have received special attention during the last decade are controlled reproduction and the formulation and manufacture of artificial feeds. The expansion of aquaculture to wider geographical areas has increased the international exchange of cultivated species, sometimes with attendant problems, and there is a necessity to control this traffic

In China and the socialist countries of Europe, aquaculture is undertaken on state farms, communes or through co-operatives. In other countries production is largely in the private sector, mainly by individual farmers. In recent years a number of small and large private companies have become involved in research and development or commercial production. Small scale operators and subsistence-level farmers are largely dependent on government agencies for support services Only in some exceptional cases have the governments been sufficiently responsive to the needs of the aquaculture industry The organizational position and the absence of a suitable legal framework have affected the provision of appropriate support to the industry Research, extension services and information exchange are areas which require special support Although there has been some increase in development assistance from UNDP and bilateral aid agencies, it falls far short of requirements

There is reason to be optimistic about global increases in aquaculture production; whether they will be of low-priced or high valued species will largely depend on national policies rather than aquaculture technology. In order to achieve a projected five- to ten fold increase in aquaculture production in three decades, massive financial investments, suitable legislation, intensive research, manpower training, development of institutions and other essential infrastructure are required. It is proposed that this Conference adopt a plan of action containing specific recommendations for implementation by well identified agencies.

La situation de l'aquaculture en 1976

Résume

La communication s'efforce de donner une vue d'ensemble des progres réalisés en aquaculture au cours de la decennie qui s'achève, ainsi que des problèmes auxquels l'industrie est maintenant confrontee.

Sur la base des informations disponibles, la production aquicole mondiale est estimée, pour 1975, à plus de 6 millions de tonnes. Au cours de la dernière décennie, cette production a constamment progressé Dans la plupart des pays, on a observé une tendance au developpement des systèmes d'élevage intensifs ou semi-intensifs.

La mise en oeuvre des plans décennaux de développement aquicole, préparés par 34 pays en développement en Afrique, en Asie et en Amérique latine, ainsi que l'augmentation de la production que l'on constate dans d'autres pays devraient permettre une production totale de 12 millions de tonnes d'ici la fin de 1985. Un certain nombre de facteurs - accroissement des coûts d'exploitation, modifications prévues du droit de la mer et necessité de reinstaller et d'employer les pêcheurs en excedent et les agriculteurs sous employés ont permis d'attirer l'attention sur l'aquaculture. D'autre part, l'augmentation du coût de la nourriture, la pénurie d'engrais, la pollution aquatique et parfois la mise en oeuvre, sans discrimination, de certains règlements visant à la protection de l'environnement ont fait obstacle à l'expansion de l'industrie.

On a assisté à un certain nombre de progrès techniques au cours de la dernière décennie. Les plus importants d'entre eux sont lies a l'amélioration et à la modernisation des pratiques traditionnelles, pisciculture en cages et en enclos/parcs, polyculture, élevage des tilapias des crevettes, des anguilles et des huitres, et recyclage des déchets par l'aquaculture, notamment par l'utilisation des effluents thermiques Les progrès de l'élevage des silures aux Etats Unis constituent sans doute un exemple intéressant de recherche technologique en vue de satisfaire les besoins en croissance rapide de la production. Le reconditionnement et la réemploi de l'eau sont devenus frequents dans les écloseries de certains pays. Avec l'amélioration des methodes employées et la demonstration de la viabilite economique des opérations, les activités de 'sea ranching' ou 'aqua range farming' constituent maintenant des techniques reconnues La reproduction en conditions contrôlées et la formulation ainsi que la fabrication des aliments artificiels constituent deux secteurs dans lesquels des recherches poussées ont eté realisees au cours de la dernière décennie L'expansion de l'aquaculture dans des zones géographiques élargies a conduit a accroitre les échanges internationaux d'espèces elevees, ce qui a parfois produit des problèmes, et il est devenu nécessaire de contrôler ces échanges

En Chine et dans les pays socialistes d'Europe, l'aquaculture est pratiquée dans des fermes d'Etat, des communautes ou par l'intermédiaire de coopératives. Dans d'autres pays, la production est essentiellement entre les mains du secteur privé et notamment de pisciculteurs individuels. Ces dernières années, un certain nombre d'entreprises privées, petites et grandes, se sont interessées à la recherche, au développement ou à la production commerciale Les petits entrepreneurs et les pisciculteurs de subsistance sont largement tributaires des institutions gouvernementales pour en obtenir des services d'appui Les gouvernements n'ont répondu aux besoins essentiels de l'industrie aquicole que dans des cas exceptionnels. La situation de l'aquaculture du point de vue organique et l'absence d'un cadre juridique approprie ont affecté la fourniture d'un appui suffisant à l'industrie. Les services de recherche, de vulgarisation et d'échanges d'informations constituent des domaines qui demandent une aide particulière Bien que l'aide au développement fournie par le PNUD et des organismes d'aide bilaterale ait augmenté dans une certaine mesure, elle est loin de faire face a tous les besoins

Il est juste d'être optimiste quant aux augmentations globales de la production aquicole: que l'on élève des especes bon marché ou onéreuses dependra essentiellement des politiques nationales et non des techniques aquicoles Afin que la production aquicole soit quintuplee, voire décuplée en trente ans, il faudra disposer d'investissements massifs et d'une legislation appropriée, réaliser des recherches intensives, former du personnel, développer les institutions et construire des infrastructures essentielles. On propose que la présente conference adopte un plan d'action contenant des recommendations spécifiques, qui devront être mises en oeuvre par des institutions bien définies.

Situación de la acuicultura en 1976

Extracto

En este documento se examinan los progresos hechos en el campo de la acuicultura durante el ultimo decenio y los problemas que actualmente tiene planteados la industria.

Basándose en la informacion disponible, la producción mundial de la acuicultura en 1975 se calcula en mas de 6 millones de toneladas. Durante el último decenio, la producción acuicola ha aumentado continuamente. En la mayoria de los paises se ha tendido a introducir sistemas de cultivo intensivos o semi intensivos.

Se espera que la ejecución de los planes decenales de desarrollo de la acuicultura preparados por 34 paises en desarrollo de Africa, Asia y América Latina, y los aumentos de produccion que se produciran en otros paises, resulten en una produccion total de 12 millones de toneladas para finales de 1985 Son varios los factores tales como el aumento del costo de las actividades pesqueras, cambios esperados del derecho del mar y necesidad de reasentar a los pescadores sobrantes y a los agricultores subempleados y encontrarles trabajo que han contribuido a que se preste nueva atención a la acuicultura. Por otro lado, el aumento de los costos de los piensos, la escasez de fertilizantes, la contaminación de las aguas y, a veces, la aplicación indiscriminada de algunas normas de

protección del medio ambiente, han impedido la expansion de esta industria.

Durante el último decenio se han producido numerosos progresos tecnológicos en la acuicultura, los más importantes de los cuales consisten en la mejora y modernización de los sistemas tradicionales, como el cultivo en jaulas y recintos, el policultivo, el cultivo de *Tilapia*, la cría de camarones, el cultivo de anguilas y ostras, y el reciclaje de desechos, incluido el aprovechamiento de calor residual. El desarrollo de la cría de bagre en los Estados Unidos constituye probablemente un buen ejemplo del intento de adaptar la tecnología a la rápida expansión de las necesidades de producción. En algunos países, el reacondicionamiento y reaprovechamiento del agua en los viveros de peces es cosa común. Al mejorar los métodos empleados y demostrarse la viabilidad económica de las operaciones, la práctica de 'sea ranching' o 'aqua-range farming' ha pasado a ser una tecnología aceptada. Dos sectores de investigación que han recibido especial atención durante el último decenio son la reproducción controlada y la preparación y manufacturación de piensos artificiales. La extensión de la acuicultura a zonas geográficas más amplias ha aumentado el intercambio internacional de especies cultivadas, lo que a veces ha planteado algunos problemas, que hacen necesario controlar esos movimientos

En China y en los países socialistas de Europa la acuicultura se practica en granjas estatales, comunas o cooperativas. En otros países la producción procede en buena parte del sector privado, principalmente de productores individuales En los últimos años, varias compañías privadas, tanto pequeñas como grandes, se han ocupado de actividades de investigación y desarrollo o directamente de la producción comercial Los productores a pequeña escala y los agricultores que viven a nivel de subsistencia dependen en buena parte, para recibir los servicios auxiliares necesarios, de agencias gubernamentales Sólo en algunos casos excepcionales los gobiernos han respondido en forma suficiente a las necesidades de la industria acuícola. La situación del sector en la estructura orgánica general y la falta de un marco legal adecuado han impedido que se preste apoyo adecuado a esta industria. La investigación, los servicios de extensión y el intercambio de información son sectores que requieren apoyo especial Aunque la asistencia del PNUD y de los organismos bilaterales de ayuda ha aumentado algo, es aún muy inferior a las necesidades.

Hay razones para ser optimistas sobre el aumento global de la producción de la acuicultura. Que ese aumento de producción corresponda a especies de poco precio o de gran valor, dependerá, en buena parte, de las políticas nacionales, más que de la tecnología acuícola. Para lograr que la producción acuícola se quintuplique o decuplique en tres decenios, como se ha proyectado, son necesarias inversiones financieras masivas, una legislación adecuada, investigaciones intensivas, capacitación de mano de obra, creación de instituciones y construcción de infraestructura esencial Se propone que la Conferencia adopte un plan de acción con recomendaciones específicas, cuya ejecución habra de confiarse a organismos claramente indicados

1 Introduction

The first global meeting on aquaculture, the FAO World Symposium on Warm-Water Pond Fish Culture in 1966, recommended that a similar meeting be held in five years' time 'to review the major changes, trends and innovations which may have occurred in this period' (Pillay, 1967). Although this FAO Technical Conference on Aquaculture is being held in ten years' time instead of the five as recommended, its objectives are generally the same as those conceived by the World Symposium. They are to synthesize on a global basis the experience gained in aquaculture development, review the state of technology for identifying the research and developmental efforts needed to improve it and to formulate strategies to overcome the major constraints on rapid expansion and intensification of the industry. The review and experience papers contributed to the Conference deal with these aspects in detail; this paper attempts an overview of the progress made in this field during the last decade and the problems that face the industry.

2 Aquaculture production

Although there has been a worldwide expansion of aquaculture activities, not much progress has been made in the collection of statistical data to evaluate its progress. Only a few countries have established suitable systems for the collection and compilation of aquaculture statistics. The highly dispersed location of production units, lack of specialized enumerators for data collection and the unwillingness of producers to provide detailed statistics have all contributed to this. However, the task of estimating production has become slightly easier in most countries, as some of the basic information is now available for making estimates, in contrast to the situation in 1966–67 when the production of fish through culture could be calculated only on a rough percentage basis. It was then estimated to be about seven per cent of the world catch of freshwater fish or 1 million tons annually (President's Science Advisory Committee, 1967). In 1970, a partial estimate was made on the basis of information collected from 36 countries: the total fish production through aquaculture amounted to 2·6 million tons (Pillay, 1972). A more comprehensive but again rough estimate was made in 1973 (Pillay, 1973) which showed that the production of fish was about 3·7 million tons and together with the production of crustaceans, molluscs and seaweeds, amounted to about 5 million tons.

For the preparation of this paper, estimates of production were requested from different countries; a large majority of them provided useful information which is included in Table I. This shows that the world production through aquaculture has now risen to over 6 million tons. Of this, 66% consists of freshwater, brackishwater and marine fish, about 16·2% of molluscs, 17·5% of seaweeds, and 0·3% of crustaceans.

Owing to the incompleteness of the previous and, indeed, even the current data, one hesitates to make comparisons. Certainly better estimates are now available for some of the countries and the coverage has also increased. However, by also using associated information, one can determine where production is increasing or declining. Although the percentage increase varies considerably, in almost all the countries there has been an increase in production during the last decade and also since the 1973 estimate. As is only to be expected, percentage increases are the highest in countries where aquaculture has been newly introduced or a new system has been adopted. The major increases have occurred in countries where sufficient importance has been given to this industry in national economic development plans and the essential investment and support services have been at least partially provided. For example, the production of farmed fish rose almost five times in a period of seven years in Japan (Japan Fisheries Association, 1975). In the Philippines it increased 32% in a period of about three years. In Poland it has increased about four times and Romania over two times in the same period. Increase in seaweed production in the Republic of Korea has been over 14 times in the last five years and in Japan over two times in that period. Except in a small number of localized cases, there have been no major problems of domestic marketing of aquaculture products, because of sustained demand. Stricter quality controls imposed by importing countries have, however, affected somewhat the export of products, such as oysters and trout, but this has led to greater attention to the environmental conditions under which culture operations are carried out and to the sanitary quality of products.

TABLE I
ESTIMATED WORLD PRODUCTION THROUGH AQUACULTURE IN 1975

Finfish	Tons
China—all provinces excluding Taiwan Province	2200000
Taiwan, Province of China	81236
India	490000
U.S.S.R.	210000
Japan	147291
Indonesia	139840
The Philippines	124000
Thailand	80000
Bangladesh	76485
Nigeria	75000
Poland	38400
Viet Nam, Republic of	30000
Yugoslavia	27000
Romania	25000
Hungary	23515
USA	22333
Italy	20500
Madagascar	17392
Germany, Democratic Republic of	16000
France	15000
Czechoslovakia	12222
Israel	12169
Denmark	12120
Brazil	12000
Germany, Federal Republic of	8900
Sri Lanka	7659
Egypt	7000
Mexico	7000
Malaysia	6559
Zaire	5000
Cuba	4500
Hong Kong	4019
Norway	3500
Austria	2500
United Kingdom	2000
Finland	1940
Belgium	1800
Tanzania	1500
Burma	1500
El Salvador	1208
Canada	1103
Greece	900
Chile	800
Uganda	700
Singapore	680
Kenya	400
Nepal	400
Venezuela	332
Switzerland	300
Ireland	207
Korea, Republic of	169
The Netherlands	129
Ecuador	90
Central African Empire	43
Cyprus	40
Ghana	40
Zambia	29
Paraguay	23
Ivory Coast	10
Puerto Rico	9
	3980492
Shrimps and prawns	
India	4000
Indonesia	4000
Thailand	3300
Japan	2779
Ecuador	900
Taiwan, Province of China	549
Singapore	105
Korea, Republic of	30
	15663
Oysters	
Japan	229899
USA	129060
France	71448
Korea, Republic of	56008
Mexico	45000
Thailand	23000
Taiwan, Province of China	13359
Australia	9200
Canada	5080
UK	3000
Spain	2289
The Netherlands	1500
Chile	870
The Philippines	782
New Zealand	700
Senegal	191
	591386
Mussels	
Spain	160000
The Netherlands	100000
Italy	30000
France	17000
Germany, Federal Republic of	14000
Korea, Republic of	5578
Chile	1260
Yugoslavia	287
The Philippines	182
New Zealand	150
Tunisia	60
	328517
Clams	
Korea, Republic of	24920
Taiwan, Province of China	13898
The Philippines	33
	38851
Scallops	
Japan	62600
	62600
Cockles and other molluscs	
Malaysia (cockles)	28000
Taiwan, Province of China	1243
Korea, Republic of	733
The Philippines	11
	29987
Seaweeds	
Japan	502651
China—all provinces excluding Taiwan Province	300000
Taiwan, Province of China	7347
Korea, Republic of	244795
	1054793
GRAND TOTAL	6102289

It is fairly well known that, despite the loud pronouncements of interest in aquafarming, only a few countries have so far implemented a well balanced development programme with adequate financial and technical support. Considering this, the increase in production now reported is certainly encouraging and justifies guarded optimism in the achievement of further increases.

Some significant changes have occurred in the general concept of aquaculture. Traditional practices being largely governed by local conditions and needs, the farmers seldom felt the need to intensify operations. Low-density culture with minimum inputs and low production per unit area has often been more economical than intensive farming which involves the rearing of dense populations and heavy inputs. Due to various reasons, this is changing fast and many countries are now turning to intensive and semi-intensive systems. For example, in Israel, fish ponds producing less than 2·5 tons/ha are no longer profitable (Sarig, 1974). Even in some of the eastern European countries that have fish farms with ponds too large for intensive culture, higher overall productivity and profits are achieved through the combination of duck raising with fish farming.

Aquaculturists now try to exercise greater control over the environment and stocks in their farms, even in what are called 'trap-ponds'. They seek to produce seed by artificial propagation and resort in most cases to at least supplemental feeding. Even in culture systems where natural food (such as algae or plankton) is raised through fertilization, improved systems of management are adopted to intensify production.

Several projections of future aquaculture production potentials have been made; one often quoted is a five- to ten-fold increase in two or three decades. As part of the preparatory activities of the FAO/UNDP Aquaculture Development and Coordination Programme, representatives of some 34 developing countries have been assisted through regional workshops in Asia, Africa and Latin America to prepare ten-year aquaculture development plans, setting out targets of production based on existing and proven systems of culture (FAO/UNDP, 1975, 1976 and 1976a). These targets, together with the production increases from other countries, are expected to contribute to a doubling of world production through aquaculture in ten years. Based on the present world production, this would amount to nearly 12 million tons by the end of 1985 and, if this pace of increase is maintained, it may be reasonable to expect at least a five-fold increase by the end of this century.

In considering the present and future production through aquaculture, it may be interesting to examine some of the

factors that have affected the industry in recent years. At least three of these have served to focus renewed attention on aquaculture in the last few years. One is the increased cost of fishing due to steep increases in fuel cost; second, the fear of decrease in fishery production by countries that depend on fishing in foreign waters as a result of new laws of the sea; and third, the need in some countries for relocating and finding alternative or additional employment for large numbers of excess fishermen or under-employed farmers. The continued high demand in developed countries for high valued species, like shrimps and prawns, has also served to promote interest in aquaculture in countries that wish to increase foreign exchange earnings. On the other hand, the steep increases in the cost of some of the essential inputs, particularly feed, have hit the intensive culture systems, as for catfish (*Ictalurus* spp.) and rainbow trout (*Salmo gairdneri*). This was largely due to the increase in the cost of fishmeal, a major ingredient in most fish feeds. Similar increase in price and indeed even of availability has occurred also for the widely used larval food, the brine shrimp (*Artemia*). The situation regarding feed prices has eased somewhat recently, although it still remains a major element in the cost of production. This has led to a search for cheap substitutes and some progress has already been reported in this direction. The shortage of fertilizers in developing countries and the allocation of all the production for agricultural purposes has also been an adverse factor.

Even though the prevailing environmental concern has resulted in increased interest in protecting the aquatic environment and has, in many cases, helped aquaculture, in some countries it had the reverse effect. Aquaculture has been classed as a polluter and waste discharge regulations meant for terrestrial animal production have been made applicable also to aquaculture. This has greatly hampered the expansion of the industry.

Water pollution has affected aquaculture production in coastal waters in some countries; for example, oyster production in Japan has remained more or less at a stagnant level since 1965 and in the United States there has been marked decrease in oyster production due to the closure of polluted oyster beds. Large-scale mortality of oysters, due to known and unknown causes in important culture areas like the French coast, has resulted in serious decline of production.

The absence of a legal framework under which aquaculture enterprises could be established and operated has also stood in the way of the development of the industry, particularly in industrially-advanced countries. Some of the problems faced by entrepreneurs in getting the necessary permits from different, only peripherally interested, agencies and the need to conform to regulations not relevant to aquaculture have been revealed in recent discussions (Loftas, 1974; Pillay, 1975).

There has been considerable interest in the private sector in investing in aquaculture but this is largely confined to the culture of exportable products and, in many cases, the technologies for such types of culture are still under development. Only a small percentage of the present aquaculture production relates to such high-valued exportable products and, therefore, the investment support for aquaculture as a whole remains at a very low level. These, together with a general lack of appreciation of the economic viability of aquaculture, have stood in the way of a speedier development of the industry. The inevitable failure of some badly conceived enterprises has also contributed to give some credibility to arguments of the detractors of aquaculture.

3 Technological advances

During the last decade, a number of technical advances have been made in the field of aquaculture and some new technologies developed. Some of the research done during this period has been extremely valuable in understanding the scientific bases of certain traditional practices and enabled the improvement and modernisation of old technologies. Cage and enclosure/pen culture are outstanding examples of this. Though such forms of culture have existed for many years, particularly in Asia and the Far East, they were not very suited for application elsewhere. Modifications or changes in the design, building materials, installation and operation, together with the preparation of suitable feeds, including floating pellets, have made these into technologies capable of being applied in other regions. Cage culture of catfish, salmon (*Salmo salar* and *Oncorhynchus* spp.), trout and yellowtail (*Seriola quinqueradiata*) and enclosure/pen culture of salmon and milkfish (*Chanos chanos*) have achieved the level of commercial-scale operations in some countries, particularly the United States, Norway, the Federal Republic of Germany, the Philippines, and Japan. Several types of cages have been designed for use under different hydrological conditions. The marked increase in the production of trout and salmon in Norway is due to the introduction of cage and enclosure culture. Cage culture accounts for a very high proportion of the present day production of yellowtail in Japan. In a period of about five years over 5 000 ha of fish pens have been established in Laguna de Bay in the Philippines, producing 7 500–10 000 tons of milkfish annually.



Fig 1 Floating cages used for fish culture in Norwegian fjords

Similarly, polyculture of fish is an ancient technology in Asia, especially China and India. Experimental work in recent years has given a fuller understanding of the significance and value of the system. This is becoming an accepted practice in the culture of Chinese and Indian carps (*Ctenopharyngodon idella, Hypophthalmichthys molitrix, Aristichthys nobilis* and *Catla catla, Labeo rohita, Cirrhina mrigala*), especially because of the increasing need for the adoption of low-energy systems. In fact, a system of combined culture of these groups of carps along with the common carp (*Cyprinus carpio*) has been developed in

India yielding up to 8 500 kg/ha with only modest supplemental feeding. Polyculture of common carp and tilapia (*Tilapia* spp.) has served to increase average production in Israel and provide an additional crop, which is of special importance from the point of view of marketing in the country because of the ceilings imposed on the production of common carp.



Fig 2 Catch from a polyculture carp farm in India

Catfish farming in the USA is a good example of the development of new technologies to keep up with rapid expansion of production requirements. Little was known about catfish farming until 1960. Research and promotional efforts were effective in developing new techniques of production and creating a demand for cultured catfish. Consequently, a considerable increase in production took place in the late sixties and early seventies. From 1966 to 1975 the area under catfish culture increased more than ten-fold; so did the production (50 223 tons valued at US $40 million). The many advances in catfish culture techniques, including breeding and fry production, feeding, pond management, disease control, and harvesting have served to develop a well advanced technology that has the potential for transfer to other areas.

Pond culture of tilapia has existed in tropical countries, particularly those in Africa, for many years. However, the problem of overpopulation of ponds and consequent stunting due to frequent breeding of this fish made tilapia culture generally unattractive. Two broad systems of culture have evolved in recent years which make culture of tilapia viable and capable of being practised on a commercial scale. One consists of the use of selected species, such as *Tilapia nilotica*, which grow fast and attain a fairly large size, and feeding them with suitable pelleted or other feeds so that the majority of the stock will attain marketable size before large-scale breeding occurs, *ie*, within three to five months (FAO/UNDP, 1973). The second is by the use of hybrids, which are all or mainly males and thus reduces breeding and overpopulation of ponds. Although neither of these systems is entirely satisfactory in overcoming the problem of prolific breeding, they do serve to raise up to 5 000 kg/ha of marketable fish a year and provide a fair return on investment. Further work on hybridization may succeed in consistently producing all male hybrids, but in the mean while it has been shown that, if tilapia were cultured in suspended cages, breeding of the stock could be eliminated.

Although traditional systems of extensive shrimp and prawn farming have existed in Asia for many years, it was only in the sixties that intensive culture based on hatchery-produced larvae and juveniles was developed in Japan. Because of the high demand for shrimps in world markets and the inability of natural fisheries to meet the demand, an almost worldwide interest in their culture has developed in the last ten years. The initial attempts made were to transfer the Japanese technology but this has not generally been successful. Significant advances have, however, been made in a number of countries, notably the United States, Republic of Korea, Taiwan Province of China, the Philippines, Indonesia, France (and Tahiti) and the UK in establishing successful methods of artificial propagation and hatchery production of juveniles of a number of *Penaeus* species. Development of techniques for the maturation of penaeid shrimps, such as *Penaeus merguiensis* and *P. monodon* (FAO, 1975; Alikunhi *et al*, 1975) has added to the efficiency of seed production. However, large-scale intensive monoculture of shrimps to marketable size on an economically viable basis has not yet developed outside of Japan, with the probable exception of Taiwan Province of China. Improvements and intensification of traditional practices in some of the southeast Asian countries, particularly Indonesia, have led to better yields in polyculture with brackishwater fishes, mainly the milkfish (Padlan, Ranoemihardjo and Hamami, 1975).

The culture of the freshwater prawn *Macrobrachium rosenbergii* on a very small scale existed in Asia, but the interest in commercial farming of this species developed as a result of the very high demand for shrimps and prawns in the world market, and of the methods devised in 1961 69 for the propagation of this species which has the advantage of a shorter life history than penaeid shrimps (Ling, 1969). Many improvements have been brought about in the technique of mass rearing of their larvae (Fujimura and Okamoto, 1972). There are now a large number of institutions, agencies and private companies worldwide engaged in research and development activities related to *Macrobrachium*. In the United States alone there were at least 25 of them in 1974 (Goodwin and Hanson, 1975). While the hatchery technology and procedures are considered adequate, high-density commercial farming techniques have yet to be perfected. Most commercial enterprises use earth ponds for production purposes and, where physical and economic conditions are favourable, some operations have been profitable. Further technological advances are needed, however, to bring prawn farming to the level of large-scale commercial ventures.

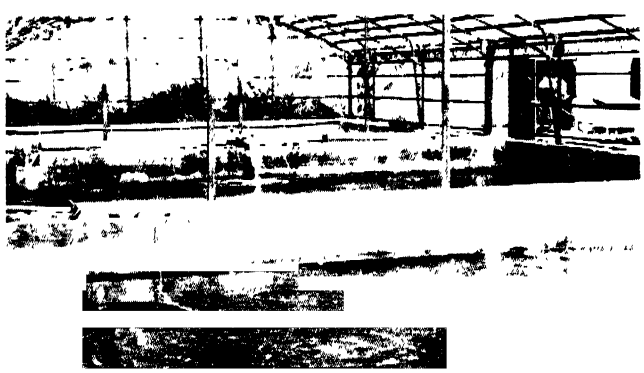


Fig 3. An indoor shrimp rearing facility in Japan

The 'hanging method' of oyster culture (in which oysters are suspended from rafts, long-lines or racks) is not really a new system, but it has during the last decade been adopted on a much wider scale in many countries and has undergone modification and adaptation. This system permits high production rates per unit area and reduces losses from predation. The use of nylon netbags for holding oysters and mussels for rearing is becoming common in some European countries.

A system of aquaculture that has received worldwide attention in recent years is the culture of eels (*Anguilla* spp.) in stagnant or flowing water ponds or in net enclosures. Although the technique of eel culture originated many years ago, it is only in the last decade that it received wide attention, largely as a result of the expansion of Japanese eel culture and a rapid increase in demand for the product. The culture technology has undergone considerable improvement, particularly in the production of satisfactory feeds which, to a large extent, accounts for the expansion of the industry in Japan. However, the culture is still based on elvers caught from the wild, and a shortage of elvers in Japan resulted in a worldwide search for new sources and the establishment of a sizeable export trade for elvers in many countries, particularly in Europe.



Fig 4 An eel farm in Taiwan Province of China

Use of domestic and farm wastes for fish culture is an age-old practice in Asia, especially in China, Malaysia and Indonesia, but it is only recently that this practice has attracted wider attention as a means of recycling wastes to protect the environment and, at the same time, contribute to food production. This has led, on the one hand, to wider use of human and animal wastes in aquaculture and, on the other, to critical studies on the benefits and risks involved. Many developing countries are adopting the system of fish farming in association with duck, pig or cattle raising so as to utilize the wastes for fertilizing fish ponds. The area of sewage-fed fish ponds in India has expanded to over 12 000 ha. Duck-cum-fish farming, which is an efficient means of recycling duck droppings, has become widespread in eastern Europe (Czechoslovakia, Hungary, Poland and Romania) and has now been introduced in the Central African Empire and Nepal. Experimental studies on the use of domestic sewage have been undertaken in some countries and the results of these are in many respects encouraging. It has been conclusively shown that productivity in aquaculture of fish or shellfish can be significantly increased by the controlled use of treated sewage for increased production of plankton.



Fig 5. Duck cum fish culture in Hungary

Experiments in the culture of shellfish fed on algae raised in sewage effluents in Woods Hole, USA have provided the basis for a 'pilot-plant' multiple-production system (Ryther, 1975). Simpler systems suited for rural communities, in which animal and domestic wastes are conditioned for use in aquaculture and also generated by-products, such as methane for use as fuel, algae as animal feed and fertilizer, have been successfully used in some of the South Pacific islands (Chan, 1974).

Another type of waste recycling in aquaculture developed in recent years and already being used on a production scale in temperate and sub-tropical climates is the use of waste heat. Extension of growing period, better feed conversions, acclimatization of organisms that cannot withstand lower temperature, and earlier attainment of marketable size or maturity have been possible through this practice.

A new technology that has developed at a rapid pace during the last decade is the reconditioning and reuse of water for aquaculture. The availability of water will become a limiting factor for aquaculture development in an increasing number of countries in the future and the cost of pre- or post-treatment may sometimes be prohibitive. These and the restrictions that are imposed on discharges from aquaculture installations have given an added significance to this technology in so far as aquaculture is concerned. As a result, several systems of water reconditioning for reuse have been developed. All of them are not equally economical, but the use of reconditioned water has become a fairly common practice in hatcheries, especially in the United States.

During recent years 'sea-ranching', 'aqua-range farming' or 'artificial recruitment', as it is variously described, has become an accepted technology in aquaculture. Some years ago attempts to improve fish populations with hatchery reared fish were generally considered unsuccessful. This concept has undergone considerable change with improvements in the methods adopted, particularly feeding, release of adequate numbers of hatchery-reared animals after they have been grown to a size when they can fend for themselves, and the recapture of a satisfactory percentage of the released fish to make the operations viable. Anadromous fish are obviously best suited for such aqua-range farming and it is estimated that over 2 000 million juvenile anadromous fishes are artificially produced annually and released into the fresh and marine waters of the world, mainly from government hatcheries. Privately-owned sea-ranching

has already made a beginning. According to recent studies in North America, for every dollar spent for the hatchery rearing and release of coho salmon (*Oncorhynchus kisutch*) smolts, the return has been seven dollars, and for chinook salmon (*O. tshawytscha*) three and a half dollars. Large scale release of hatchery-reared *Penaeus japonicus* in the Inland Sea of Japan is believed to have resulted in substantial improvement in the local shrimp fishery with a cost benefit ratio between 2:5 and 2:20. Appropriate and ade quate stocking operations have led to the improvement of fishery resources of many reservoirs and natural lakes.

When considering the techniques *per se* two major problem areas have received special attention during recent years: the controlled reproduction of cultivated animals: and the formulation and manufacture of artificial feeds. The Chinese carps, Indian carps, and the grey mullet (*Mugil* spp.), which do not generally breed in confined waters of culture installations, have been induced to breed by the administration of pituitary hormones. Induced breeding by pituitary injections or adjustment of photoperiod has become a recognized practice in fish culture and a number of cultivated and cultivable species have been bred experimentally. Methods of mass rearing of fish larvae have also been developed and these are now being employed by culturists in the case of Chinese and Indian carps. One of the early advances in shrimp culture technology was their artificial propagation based on gravid females collected from the wild. Collection of an adequate number of breeders at the required time is often expensive and difficult. Conse quently, the successful maturation of shrimps in captivity in the laboratory by eyestalk ablation is a breakthrough of considerable significance, but much more remains to be done to perfect this technique for large-scale application (FAO, 1974; Alikunhi *et al*, 1975). Similarly, the con trolled reproduction of oysters and hatchery production of oyster seed is a development of considerable significance in oyster farming, particularly because the supply of seed oysters from natural reproduction is decreasing due to environmental degradation and imported seed has become quite expensive. These circumstances contribute to making hatchery production of seed economically viable in countries like the United States. Controlled reproduction has also helped in genetic selection of strains for special qualities, such as resistance to diseases.

With the expansion or introduction of aquaculture in wider geographical areas, international exchange of cultivated species has become widespread. This has given rise to considerable controversy about the introduction of non-indigenous species, some considering it unavoidable for rapid expansion of aquaculture, others being terrified by the possible adverse effect of introductions on local fauna and flora. While introductions into certain countries or areas have been totally banned, indiscriminate introductions con tinue in others. Though appropriate and adequate guide lines are still lacking, scientists and many aquaculturists accept the need for extreme care and for critical study of all relevant environmental and behavioural information before deciding on such introductions. Recognition of the dangers of transmission of communicable diseases through shipments of live organisms has led to the consideration of an international convention to control the spread of communicable fish diseases (Dill, 1972; FAO, 1974a) and a draft convention is now under consideration by interested countries.

4 Organization of aquaculture

A good proportion of current fish production through aquaculture comes from China and the socialist countries of Europe. In these countries fish culture is undertaken on State farms, communes or through cooperatives and, because of its role in communal welfare, the industry seems to receive special attention. In others, particularly industrially-advanced countries, aquaculture production is largely undertaken by the private sector. Individual farmers dominate the scene, but many small and large companies have, in recent years, become interested and involved in research and development activities or commercial produc tion. An incomplete survey in 1975 revealed the existence of some 833 companies in 26 countries, the majority of which are in North America, Japan and Western Europe. In developing countries most of the production is still in the hands of small-scale operators or subsistence level farmers, although there are also some instances of involvement by large commercial firms. They are in most cases dependent on the government agencies for support services, including technical and financial assistance. Only in some exceptional cases have the governments been sufficiently responsive to the needs of the aquaculture industry. Because of the anomalous legal status of aquaculture—not being recognized as an agricultural, animal husbandry, or truly fishery activity in the legal sense to be eligible for governmental support and other incentives—the aquaculturists face formidable problems in establishing or operating their enterprises. Nevertheless, restrictive legal provisions designed and relevant only for other industries are readily applied to aquaculture, as for example the application of waste disposal and disease control regulations meant for animal husbandry. Although in some countries, such as the USA and the UK, aquafarmers are organizing themselves and attempting to influence governmental policies, in most others they do not have the political or social influence to force governmental action necessary to solve the problems of the industry.

In governmental organizations aquaculture forms part of the fishery sector. The tertiary phase of aquaculture industry has close similarity with that of the fishing industry but since the production phase is more allied to agriculture and animal production, there is a large body of opinion favouring better linkage with these forms of food production, in order to benefit from allied experience and from the many incentives offered for their promotion by governments. With increasing public interest and the modest increases in investments, a distinctly negative attitude and rivalry appear to be developing between aquaculture and conventional fisheries interests. This is an unfortunate and unnecessary situation, as at least in the foreseeable future there is little likelihood of aquaculture supplanting conventional fishing. On the other hand, the world demand for fishery products is increasing steadily and it is generally accepted that it will not be possible to meet the demand by conventional fishing alone. Change that may be brought about in the marketing and price structure due to enhanced production through aquaculture has to be accepted as a healthy development and through proper integration of production and marketing, stability can be ensured in both sectors.

Research and extension are two major support services required to be provided by governments in most countries. There has undoubtedly been considerable interest in aquaculture research in many developing and developed

countries. The number of experimental stations in developing countries has certainly increased, though very few of them have adequate research personnel, equipment and other essential facilities. In many developed countries, research on aquaculture problems has expanded due to financial support available from funding agencies. It has generally been recognized that close co-ordination of research, which is highly diffused at present, is essential to obtain maximum benefit from the investment and effort expended. The multidisciplinary nature of aquaculture science and the need for teamwork to undertake systems-oriented research to improve or develop new aquaculture systems is gradually being understood.

One of the weakest areas of aquaculture activities at present is extension services, which creates serious problems in the implementation of development programmes. This is very much connected with the shortage of adequately trained and experienced field personnel who have the ability and knowledge to assist aquafarmers. The large majority of aquaculture personnel employed in government organizations and in senior positions even in the industry, are those who developed their knowledge of the subject through specialized research and then tried it in the field, often learning by trial and error. This is no doubt a costly and slow means of acquiring expertise for large-scale development programmes. Recognizing this, some of the countries have established extension training centres. There is an urgent need to upgrade the facilities for well balanced theoretical and practical training in these centres to meet the requirements for extension personnel. The regional symposia and workshops organized by FAO during the last ten years have emphasized the need for accelerated co-operative efforts in establishing multidisciplinary research programmes and training of core personnel including extension staff.

Information exchange has a vital role in a developing science like aquaculture, particularly since the industry has to depend to a large extent on transfer of technology for its expansion. During the last decade, a number of periodicals including 'Aquaculture', 'FAO Aquaculture Bulletin', 'The Commercial Fish Farmer and Aquaculture News', and 'Fish Farming International' have come into being. While these, together with a number of recent books, represent significant progress, they only fulfil a small part of the information needs. The National Aquaculture Information System (NAIS) sponsored by the Sea Grant Program in the USA, which has started a computerized file of information on the subject, is a good beginning in information collection, storage and dissemination.

Those who have been concerned with extension work will know the serious difficulties experienced in the field for lack of suitable literature and particularly audio-visual aids for farmer education.

5 Development assistance

While it is generally recognized that massive assistance is required for rapid progress in aquaculture, the flow of development assistance in this sector has, unfortunately, been very insignificant. Sources of assistance for general agricultural development are multiplying and some of them have indicated in principle their ability to assist aquaculture, but as yet very little support has materialized.

The United Nations Development Programme has been, so far, the major source of technical assistance in aquaculture. In the early part of 1976 there were some 35 operational large- and small-scale projects and about 12 projects in the pipeline for implementation through FAO. Since aquaculture projects have to be accommodated within the total allocation of development assistance for each developing country and there is severe competition between different sectors, including sectors within agriculture and even within fisheries, the claims of aquaculture are often overlooked or sought to be met with token allocation. FAO's Freedom From Hunger Campaign/Action for Development (FFHC/AD) and the World Food Programme (WFP) have given some assistance to aquaculture. The United Nations Children's Fund (UNICEF) continues to give limited aid for fish culture development through its FAO/UNICEF Applied Nutrition projects in Bangladesh, India, Indonesia, and the Republic of Korea in the form of equipment, training facilities and, in some cases, technical assistance.

In earlier years small projects were useful to show the potential of the aquaculture industry but now the need is for projects capable of demonstrating its technical and economic feasibility in order to attract investments for large-scale development. The funding available for the majority of projects, from national or international sources, is too inadequate to achieve this objective. One is often inclined to think that it is a mistake to undertake such projects that have little chance of achieving their objectives, as their performance will be held against future assistance to aquaculture.

The concept of assistance projects providing 'seed money' for activities to be supplemented by contributions from bilateral or other sources has gained wide acceptance from funding agencies in recent years. This has apparently worked successfully in certain sectors but has few precedents in aquaculture. Many of the bilateral aid agencies that welcome co operative efforts have yet to show positive interest in this field, as for example the Swedish International Development Authority (SIDA), the Norwegian Agency for International Development (NORAD), and the Danish International Development Agency (DANIDA). The lack of expertise in aquaculture, or in tropical aquaculture, either in the agency concerned or in the donor country, is sometimes advanced as a reason for this; there may also often be other reasons, including competing demands from more familiar or appealing sectors.

Detailed information on current bilateral aid for aquaculture development is not readily available. The United States Agency for International Development (AID) provides assistance to at least six countries in fish culture research and training. Besides supporting the Aquaculture Department of the Southeast Asian Fisheries Development Center (SEAFDEC), Japan also provides technical assistance to a small number of developing countries. Canada (through the Canadian International Development Agency, CIDA), China, India and Israel are other countries involved in aquaculture development assistance.

The International Development Research Centre (IDRC) has in recent years become active in promoting research in developing countries and now has projects in at least five countries. The International Foundation for Science (IFS) in Sweden provides assistance to young scientists to carry out research in developing countries and supports at present 24 investigations. The International

Center for Living Aquatic Resources and Management (ICLARM), a newly-established Agency sponsored by the Rockefeller Foundation, has support to aquaculture development as one of its objectives.

The main international sources of financing for aquaculture are the World Bank Group, the Regional Development Banks and possibly the FAO Bankers Group. While aquaculture conforms very admirably to the new trend in World Bank assistance to support projects designed to upgrade the living conditions of the poorer sections of the society, the quantum of assistance that has materialized so far is insignificant. The developing countries represented at the Regional Aquaculture Planning Workshops in Africa (Accra, 1975), Asia (Bangkok, 1975), and Latin America (Caracas, 1975) expressed serious concern about this. To some extent the aquaculturists have to take the blame for this. Most of the data which they can present relate mainly to the fascinating techniques of breeding the animals and rearing them under different environmental parameters. Unfortunately such data alone leave the bankers quite unimpressed. There is an urgent need to accumulate more economic data and to undertake detailed feasibility studies for the preparation of projects for bank financing.

6 Outlook for the future

As indicated earlier, available production estimates show steady increases in many countries. Areas under aquaculture are expanding and improvements in technology are making it possible to intensify production and obtain higher yields. The fact that annual yields range between a few hundred kilogrammes/hectare and over 20 tons/hectare shows what improved technology and provision of essential inputs could achieve in terms of increased production. New systems of culture to be developed through research and experimentation will also contribute to increased production in the future. Even using the existing technology it is expected that a doubling of world production can be achieved in the next ten years. The area under aquaculture now is estimated to be in the order of three to four million hectares. A ten-fold expansion of this area is considered feasible if the necessary investment becomes available. Improvement of techniques has already shown the possibility of increasing average production at least two to three times per unit area or unit volume of water in a relatively short period of time. One can, therefore, be reasonably optimistic about global increases in production, even though the rate of increase in individual countries or through individual systems of culture may vary considerably. Such an expansion of aquaculture is bound to increase the availability of acceptable animal protein foods to the people. Whether it will be equally available and within the reach of all segments of the population will largely depend on national policies rather than aquaculture technology.

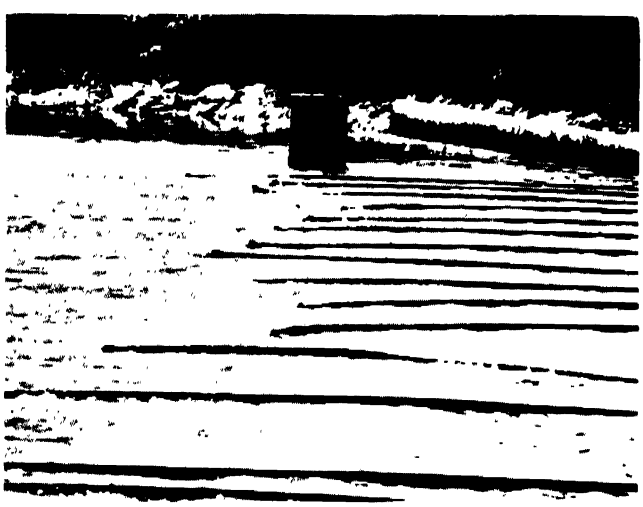


Fig 6. A view of a fish pond in Israel, used for very intensive carp culture, involving dense stocking, artificial feeding and aeration

There are species and systems of culture to produce aquafoods at prices that the 'common man'—if that species can be identified!— can afford. There are also high-valued species and systems of culture to meet the needs of the luxury market and for export to earn foreign exchange. It could become a major element in integrated rural development and serve to generate employment for a good many un- and under-employed people in the rural areas of developing countries, and thus help to arrest the drift of populations to urban areas and mitigate the problems faced in the cities due to this. Wider application of aquaculture techniques for artificial recruitment and transplantations could help to build up new fishery resources or enhance existing stocks, giving rise to what is referred to by some as 'farmed fish fisheries'. It can contribute to the development of sport fisheries and baitfish production for commercial or sport fishing. Mention should also be made of the possibility for the expansion or introduction of pearl culture in many countries. Greater use of inland and coastal waters for aquaculture would also inevitably involve effective measures for protecting the aquatic environment. It could provide efficient means of recycling agricultural and domestic wastes and thus help in general waste disposal and environmental protection. Besides all these benefits, it is well worth recognizing that aquaculture denotes a step in man's evolution from a hunter to a herdsman and husbandman. Aquaculture, therefore, deserves to be considered from a wider angle than that of only the increased production of animal protein or the creation of economically viable enterprises.

The planned doubling of production in the next ten years or the five to ten-fold increase in three decades will need accelerated transfer of technology, massive financial investments, suitable legislation, intensive research, manpower training and development of institutions and other essential infrastructures. If these are left to evolve through the inner pressures of an emerging industry, much valuable time will be lost and it will take many more years for the industry to fulfil its potentials.

It is, therefore, of utmost importance that this world conference decides upon an appropriate plan of action to accelerate the development process. It should reflect the determination of governments and the world community to elevate aquaculture to an appropriate level in national and international priorities. Specific recommendations for implementation by well identified agencies should be outlined and the unequivocal support of international, inter-governmental and non-governmental agencies sought to enhance development assistance.

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Aquaculture and Integrated Rural Development, with Special Reference to Economic Factors

G. M. Gerhardsen

Abstract

As aquaculture production can be increased to a considerable extent, properly planned and managed development should be able to contribute considerably to an increase in food supplies. By improving the physical well being and quality of life of the rural poor, their productivity and ability to contribute to the national economy may be enhanced.

Viability is the leading principle on which aquaculture development should be based and a variety of yardsticks should be used The socio economic importance of aquaculture may be assessed by the added 'value' which is produced and that portion of it which is retained in rural areas. To this end adequate marketing must also be arranged.

In order to achieve maximum results the various factors of production and their interplay must be studied and appropriate steps taken for both vertical and horizontal integration of the operative enterprises In the majority of developing countries there will probably be, all factors taken into account, a strong bias toward small-scale and labour-intensive enterprises

In many respects aquaculture cannot and should not be considered as a separate rural activity Many amenities can be provided jointly for various professional groups. There is, however, a specific need for specialized research and education and training and, in many areas, aquaculture demonstration farms and realistic extension service should be established. For the small aquaculturists, in particular, it would be very useful if provision could be made for a 'package' containing both technical advice, assistance in organizing supplies of construction materials, fish seed and feeding material and, not least, institutional credit on reasonable terms both for investment and operational purposes

At the government level, care must be taken in establishing realistic 'quantified objectives' with regard to labour remuneration, quantity to be produced, employment and ownership, *etc.* Government participation will normally have to include surveys of national resources, the provision of national and international technical assistance and general and special services and infrastructures.

L'aquaculture dans le développement rural intégré et en particulier les facteurs économiques

Résumé

Etant donné que l'on peut accroitre notablement la production de l'aquaculture, un développement convenablement conçu et aménagé devrait permettre d'augmenter considérablement les disponibilités alimentaires. En améliorant le bien-être physique et la qualité de la vie des populations rurales défavorisées, l'on peut stimuler leur productivité et leur aptitude à fournir un apport à l'économie nationale

La viabilité est le principe majeur sur lequel doit être fondé le développement aquicole et plusieurs critères s'imposent à ce propos. L'on peut mesurer l'importance socio-économique de l'aquaculture par la valeur ajoutée produite et par la portion de cette valeur dont bénéficient les zones rurales. A cette fin, l'on doit aussi aménager des débouchés adéquats.

Afin d'obtenir les résultats maximaux, il convient d'étudier les divers facteurs de production et leur interaction, et de prendre les mesures appropriées pour favoriser une intégration tant verticale qu'horizontale des entreprises. Dans la plupart des pays en développement, il existera probablement, tous facteurs considérés, un penchant favorable aux entreprises de petite échelle à fort coefficient de main-d'oeuvre

A de nombreux points de vues, l'aquaculture ne saurait et ne doit pas être considérée comme une activité rurale distincte L'on peut procurer nombre de facilités à divers groupes professionnels dans un cadre commun. Toutefois, il existe un besoin spécifique de recherche, d'enseignement et de formation spécialisés et, en de nombreuses régions, l'on devrait établir des fermes aquicoles de démonstration et des services de vulgarisation. Pour les petits aquaculteurs en particulier, il serait très utile de mettre au point un plan global offrant à la fois des conseils techniques, une aide pour l'approvisionnement en matériaux de construction, en oeufs et alevins de poisson et ainsi que produits d'alimentation et, ce qui n'est pas le moins important, des crédits institutionnels à des termes raisonnables pour couvrir tant les investissements que les frais de fonctionnement

Au niveau gouvernemental, on veillera à établir des objectifs "quantifiés" réalistes en ce qui concerne la rémunération du travail, les quantités à produire, l'emploi et la propriété, etc. La participation des pouvoirs publics devra normalement inclure la prospection des ressources nationales, l'octroi d'une assistance technique nationale et internationale ainsi que la mise à disposition de services et d'infrastructures d'intérêt général ou spécifique.

La acuicultura en el desarrollo rural integrado con alusión especial a factores económicos

Extracto

Dadas las posibilidades de aumentar considerablemente la producción

de la acuicultura, un desarrollo bien planeado y administrado de la misma podría contribuir en forma notable a aumentar los suministros de alimentos. La consiguiente mejora del bienestar físico y de la calidad de vida de las masas pobres de las zonas rurales aumentaría su productividad y su posibilidad de contribuir a la economía nacional.

El principio capital en que debe basarse el desarrollo de la acuicultura es su viabilidad, y para determinarla pueden utilizarse diversos parámetros. La importancia socioeconómica de la acuicultura puede estimarse mediante el 'valor' añadido que produce y la proporción del mismo que permanece en las zonas rurales. Para ello es preciso organizar adecuadamente el mercadeo.

Para lograr resultados óptimos es necesario estudiar los diversos factores de producción y su interrelación y tomar medidas oportunas para la integración vertical y horizontal de diversas actividades. En la mayoría de los países en desarrollo, teniendo en cuenta todos los factores, la balanza se inclinará probablemente en favor de las empresas a pequeña escala y con gran empleo de mano de obra.

Desde muchos puntos de vista, la acuicultura no puede ni debe considerarse como una actividad rural aparte. Muchos de los servicios pueden servir al mismo tiempo para diversos grupos profesionales. Son necesarias, en cambio, investigaciones especializadas y actividades de enseñanza y capacitación de carácter específico, y en muchas zonas es preciso establecer granjas acuícolas de demostración y servicios de extensión que tengan una base realista. Por lo que se refiere a los pequeños acuicultores, en especial, sería altamente útil facilitarles un "conjunto" de asistencia que incluya asesoramiento técnico, ayuda para organizar el abastecimiento de material de construcción, peces para semilla, y piensos, sin olvidar la concesión de créditos en condiciones razonables para costear las inversiones y los gastos de operación.

A nivel gubernamental, es necesario establecer "objetivos cuantificados" realísticos sobre remuneración de la mano de obra, cantidad que ha de producirse, empleo y propiedad, etc. La participación de los gobiernos habrá de incluir, de ordinario, estudios de los recursos naturales, asistencia técnica nacional e internacional, y servicios e infraestructuras de carácter general y especial.

1 Introduction

The purpose of this paper is to assist in clarifying the role which aquaculture may play in integrated rural development efforts. Rural development programmes or projects are, as pointed out in the World Bank Sector Policy Paper (1975), 'intended to provide a sustained increase in the output and level of living of a significant proportion of the rural poor.'. Any programme of rural development must, therefore, embrace a wide range and mix of activities. To increase food supplies for domestic and export markets is the basic macro-economic purpose.

The magnitude of the industry as expressed in production quantities is affected by limiting factors which will influence the possibilities of development.

The main factors are: (*i*) natural resources; (*ii*) labour and management; (*iii*) capital and technology. The objectives and measures chosen for developing aquaculture will highly influence the standard of life for those engaged in this industry as well as in associated industries.

In this paper an attempt is made to elucidate, from an economist's point of view, the most important factors of production in aquaculture and ways and means of influencing these factors. It further purports to enumerate the main constraints, and to discuss possible ways and means of increasing production by developing viable enterprises within the framework of an integrated approach.

Development is thus an interplay between objectives, resources and measures.

The contribution which aquaculture already makes to the world's fish production is not insignificant– probably some 5–10 million tons or some 10% of total production—but, as vast possibilities are as yet not fully utilized, it is the author's contention that when properly planned, co-ordinated and integrated, expansions and improvements in the field of aquaculture may assist greatly in achieving the aims of rural development.

Over the last 10 years or so it has been recognized that when a country's economic growth is speeded up, a more equitable distribution of income does not necessarily follow. Experience has shown that in countries which have managed to achieve a high rate of growth the poorest part of the population has benefited very little—if at all. Growth-oriented development strategies of the past have, therefore, been seriously questioned. It has even been claimed that in many developing countries economic growth has led to increased inequality in the distribution of income.

The equitable distribution of income has become a major public concern and it has been realized that rural development must receive much more attention. In this effort, improved food supplies and basic services such as health and education can improve the physical well-being and quality of life of the rural poor, and indirectly enhance their productivity and their ability to contribute to the national economy. It is concerned with the modernization and monetization of rural society and with its transition from traditional isolation to integration with the national economy.

Aquaculture embraces a wide range of activities from extensive 'sea-ranching' and management activities in large bodies of water to intensive culture with fertilization and feeding of fish in small man-made ponds. It is carried out in tropical as well as semi-arctic climates and a number of problems cannot, therefore, be covered in a paper of this kind. But it is hoped, nevertheless, that the paper will provide the framework for a discussion of basic problems.

Aquaculture has developed in various parts of the world under different natural and socio economic conditions, but generally speaking, as pointed out by Pillay (1973), the interest is now mainly directed toward the establishment of viable industries irrespective of social and economic differences.

The purpose of this paper, then, is to assist in formulating programmes for the development of that sector of rural industrial life which is commonly known as aquaculture (fish farming). Emphasis is placed on activities which produce species that are reasonable in price and have a wide acceptance among all social and economic groups in the respective countries.

In the paper a simple system is presented for assessment of viability, in the widest socio-economic context. True, in some cases it may be found that maximum profitability should not necessarily be the aim; there are so many roles which aquaculture may play in a community. But viability is the leading principle on which development planning should be based. The orientation must therefore be clearly toward increasing production and raising productivity, so that aquaculture may contribute, jointly with the other rural activities such as agriculture and fishing, to the improvement of health, education, housing, nutrition standards, and other social values in rural areas.

Many sciences are involved and must be called on for the development of aquaculture. To some people the main problem may appear as being biological or technological; to others socio-political or legal. There is a clear need for research in a number of fields at a fairly high level of sophistication. Emphasis may vary from one country to another and which factor is the most important may be a moot point. The main purpose of this paper, however, is to emphasize the socio economic purpose and the need for a simultaneous and balanced approach.

While in the past progress with rural development projects—as pointed out by the World Bank—have often been disappointing, owing to lack of knowledge, incomplete understanding and limited institutional, technical and financial capabilities, the future outlook has many promising features. It is firmly believed that 'rural development schemes benefiting large numbers of people can be as productive and economically attractive as schemes of a conventional kind directly benefiting far fewer people'.

2 Possible objectives for development of aquaculture

While there may be many objectives for development of aquaculture, the main one is to produce food and preferably animal protein food and thus improve dietary standards. This is especially important in areas where other protein resources are few and insufficient; these might benefit relatively more from a possible increase of fish supplies resulting from development of aquaculture.

Production of animal protein is energy demanding. If different sources of protein are compared, then production of fish protein comes out rather favourably in terms of efficiency of energy conversion. It could be a useful source of protein both as subsistence production and in market economies. From the global viewpoint, the difference in the economic structure and immobility of labour and capital has the effect that resources are not optimally utilized. Much remains to be done, therefore, with regard to the most economical operation of aquaculture.

Natural resources such as water, fertilizers and feed are factors of production which are the first to become scarce. Labour is plentiful and, with respect to technology and capital, it is, hopefully, only a question of time until these production factors will be abundant relative to natural resources even in developing countries. In the long run, therefore, only those areas where natural resources for development of aquaculture are abundant or well suited can there be any expectation of significantly increased production.

Within an individual country, three main groups would be interested in aquaculture, and the possible objectives of aquaculture as considered by these groups could be:

(a) *Society*: (Macro economic point of view): (i) Optimal resource allocation to produce food directly or indirectly for human consumption; (ii) Encouragement of rural settlement through increased standard of living by the best possible total profitability of the industry; (iii) Creation of production surplus for export.

(b) *Producers*: (Micro-economic point of view): (i) Small-scale producers. Maximize income by greatest possible difference between production revenues and production cost; (ii) Large scale producers. Maximize return on investment.

(c) *Consumers*: (i) Plentiful food supplies at low or reasonable prices.

Production of food for direct human consumption is without question the most important objective. Indirectly, aquaculture can greatly contribute to the same objective by improvement of natural stocks through artificial recruitment and transplantation.

Other purposes of production as, summarized by Pillay (1975), are: (*a*) producing sportfish; (*b*) producing bait for commercial and sport fishing; (*c*) producing ornamental fishes; (*d*) recycling organic waters; (*e*) producing industrial fish or fishery products (*eg*, for reduction to meal or fertilizers; seaweed for marine colloids; oysters for cultured pearls).

Formulation of the long-range macro-economic objectives of aquaculture is a political decision which should balance the different interests in order to attain the greatest possible benefits for all people.

Society is therefore interested in neither overproduction nor underproduction. Over-production, which cannot be sold in the home market and cannot be exported at profitable prices, represents a waste of production resources. Conversely, underproduction may result in high prices, insufficient food supplies, poor utilization of resources and contribute to unemployment in general.

Different targets of aquaculture may easily be incompatible (targets are defined as quantified objectives). Examples of targets are: (*a*) production quantities; (*b*) employment in number of persons; (*c*) income per yearly man-hours; (*d*) size and number of enterprises; (*e*) productivity of resources utilized.

No such targets can be set in isolation but have to be established in the natural and socio-economic setting of the area concerned and with an eye to the means available for implementation of a development programme. The various development objectives are to a high degree interrelated, and considerations of the most suitable economic and technical level and the level of productivity must be carried out in a simultaneous evaluation of all relevant factors.

If a minimum profitability and income are not attained, other objectives can hardly be achieved. If, therefore, aquaculture is to contribute to enhancement of the standard of living in rural areas, its ability to pay wages, as calculated per year of work, should be at least the same as for other rural activities and thus preferably exceed the prevailing opportunity cost of labour.

The objective of the individual fish farmer may be either to maximize income or to maximize return on investment. In the case of income maximization the fish farmer seeks to achieve this objective by one of two possible ways:

(i) With given resources, he tries to maximize his production, *ie*, in terms of cost and income with given production cost, he tries to maximize production revenues.

(ii) With a given production he tries to achieve it by using the least possible resources. In terms of income and cost, with given production income, he tries to achieve it with least possible costs.

In the case of the small-scale farmer, the resources are often scarce and there are very limited possibilities to extend these. That particular production resource which is first fully utilized sets the limit for his production. In many densely populated rural areas both water and land are the limiting factors. Maximization of return on investment is most often the objective of large-scale enterprises where the engagement of the owner is limited to the management of the operation. By facilitating access to capital and technology these farmers can acquire or extend natural resources to optimize the size of the farm or operation to achieve greatest possible return on investment.

The objectives referred to above mainly deal with income and profitability. If the natural resources available for aquaculture are to be effectively utilized, the participants of the industry must live close to the production site and be actively engaged in the production process. The choice of

site of living is not only a question of the economy of the industry but also a question of social and human conditions of the local society. Aquaculture can only be developed as a viable industry if both objectives of profitability and those of social welfare are fulfilled.

3 Basic economics of aquaculture

3.1 *Aquaculture in the rural economy*

In both industrialized and developing countries there has been for some time a persistent drift from rural areas to towns. Rural areas have been drained of human resources and towns have become overcrowded. The reason for this shift away from rural life is first and foremost a lack of job opportunities in rural areas. Aquaculture may constitute, therefore, an attractive alternative in this respect.

When analysing the reason behind recent developments one must ask why terms of trade have turned against traditional rural activities. The reasons are probably to be found in the changes which have taken place in technology, in political factors, and in the relationship between population and natural resources. There is a trend toward specialization and division of labour and this will gradually transform rural subsistence economy to a commercialized production economy in which prevailing prices of output and of input in the primary industries highly influence income level in these industries. Despite the adverse effect which they might have, technological innovations can hardly be arrested or, even less, reversed, and in the long run they will reduce real production costs and thus improve standards of living.

The supply of agricultural and fishery products is often characterized by instability causing fluctuations in prices and income. This is due to inelasticities in supplies and demands with regard to price fluctuations.

In developed countries in particular, demand for staple food generated by growth in population or income tends to be less than the increased supply created by productivity improvements. Thus, free prices fall and farm incomes deteriorate. With inelastic price and income demand, prices fall for a dual reason. Small shifts in quantities generate large price fluctuations.

Some aquacultural products are regarded as luxury items in the household budget while others form part of the daily diet. Accordingly, it must be assumed that demand elasticities in prices will show great variations. As food prices, to a great extent, determine the level of living standards, the authorities in many countries regulate food prices, thus influencing, indirectly, income in the primary industries of which aquaculture is a part. Changes in rural economy are very much a political question, not only as far as prices of output are concerned, but also with respect to decisions which, directly or indirectly, influence factor prices.

When comparing the various countries where aquaculture may be carried out, one of the main economic problems is the uneven distribution of natural resources. Ownership of land may be such so that a great portion of the land is owned by a few people. This may augment the problem of efficient use of natural resources and improvement of the rural income distribution.

Low educational standards in many rural districts are another serious hindrance to progress. Innovations are difficult to implement and are often met with scepticism. Lack of education is also a barrier for participation in political decisions which in turn might pave the way for technological and economic progress.

The question of structural rationalization, leading to a determination of the optimal size of the fish farms, may also entail a reduction in total employment and an increase in *per caput* production.

3.2 *Development and growth*

Economic development, or growth, as measured by changes in the Gross National Product (GNP), is a many-sided process which influences both economic and social aspects of society. It implies a change from an initial situation to a future stage and it is in this sense that aquaculture development and rural integration problems must be regarded. Clearly, the aim is to have a 'sustained increase in *per caput* output and incomes and greater equity in the distribution of the benefits of growth' (World Bank, 1975), and it is with these objectives in mind that the growth and development problems of aquaculture should be reviewed.

The direction and intensity of the development process in these fields are highly dependent on the initial stage of the industry, and the society at large, and on the general and special objectives for future development. Development in a society does not necessarily involve increasing the production volume in all fields of endeavour; theoretically, development can take three directions: expansion, stagnation or contraction.

Stabilizing or reducing the production volume may, under certain circumstances, be necessary in order to attain objectives like increased income for those engaged in aquaculture. Depletion of natural resources and pollution are two additional examples of possible reasons for such policies. However, taking all factors into account, aquaculture is a field in which an expansion is most likely to take place. As pointed out by the UN World Food Conference (1974), much of the potential area for expansion of aquaculture consists of mangrove swamps, estuaries, lagoons, lakes and shallow coastal waters, and there is very little competition for space between aquaculture and other rural activities.

In the process of development, external events may indirectly affect aquaculture. In traditional fisheries, many fish populations are being overexploited, resulting in a decline both in catches and in the yield per unit of effort. In some areas there are examples of catches being seriously affected by pollution. Recycling of organic wastes and purifying water are also continually increasing problems throughout the world. Many countries may soon be enacting 200-mile exclusive economic zones, thus reserving some of the world's major fishing areas for the adjoining coastal states. These factors all have indirect implications on the growth or development potential for aquaculture, both in absolute terms and relative to traditional fisheries.

The development of aquaculture as expressed in growth potentials may take place in four main areas: (*a*) new markets; (*b*) new products; (*c*) improved efficiency; (*d*) restructuring present activities.

If economic growth is to be accompanied by a more equitable distribution of income, better knowledge of basic economics of production and marketing is essential.

3.3 *Model for economic analysis in aquaculture*

For analytical purposes, a simple model is proposed. The

model contains the most important technical and economic data pertaining to production and it can be used for analysing both a specific type of production, the total production of an enterprise, or the total production of a region. An example, calculated to illustrate how the figures can be arrived at, is set out in the model. In this case, the model is based on the fish production of a theoretical aquaculture enterprise in Norway.

With this model it is possible to analyse the different factors influencing the economy of aquaculture. The 'added value' in this model is the total of wages, salaries, interests and profits. Profitability indicates how effectively the various factors of production such as labour, capital, environment, species, *etc*, are co-ordinated and managed. Various measures of profitability may be calculated. In most cases the remuneration of one specific input factor is calculated and it is assumed that all the other factors receive a 'normal' remuneration. The calculation then shows the yield of the selection factor.

When making such calculations for capital, the most common measure of profitability is 'return on investment'. This measurement is the most appropriate one when capital is the minimum factor, as is the case in most rural areas, especially in developing countries. Another measurement is the ability to pay wages and this is best suited to show the remuneration which labour may receive. It can easily be used to compare the profitability of one's own performance with that of other alternative occupations and types of production. It must be stressed, however, that return on investment, and the ability to pay wages per hour, both measure the same phenomenon but from different points of view. For lending institutions, return on investments is the most appropriate measure for judging the soundness of an investment.

Land rental the economic rent—is arrived at by deducting 'normal' remuneration for own labour and 'normal' remuneration for total capital from 'profit before remuneration for own labour'.

Model for Economic Analysis in Aquaculture

Volume of water				20 000 m³
Fish produced[1]				160 000 kg
Maximum production capacity				200 000 kg
Gross operating income (sales)			N.kr[2]	2 500 000
−Variable production costs	N.kr	1 375 000		
−Variable labour costs	N.kr	500 000		
			N.kr	1 875 000
Gross profit			N.kr	625 000
Salaries	N.kr	65 000		
−Indirect costs	N.kr	200 000		
Interest on debts	N.kr	100 000		
−Depreciation	N.kr	50 000		
			N.kr	415 000
Net profit or operating income			N.kr	210 000
Total man-hours[3]				26 000
Total investment			N kr	1 805 000
Return on investment				17·2%
Ability to pay wages				N.kr 29·81/hour
Investment per employee per year[3]				N kr 138 000
Investment per kilogramme produced				N.kr 11·28/kg
Production per employee per year[3]				12 300 kg
Production per cubic metre of water				8 00 kg/m³
Utilization of capacity[4]				80%

[1] 'Production' is defined as quantity of fish sold plus increase or minus decrease in stocks of fish. This is the quantity from which the operating income is calculated

[2] US$ 1 00 N.Kr 5·5.

[3] Yearly man hours per employee = 2 000 hours.

[4] Utilization of capacity means the calculated maximal production in kilogrammes in relation to the achieved production in kilogrammes for the period under review

The rent of land can be calculated on the basis of the theoretical model drawn below:

Cost of wages and salaries:		N.kr 565 000
Operating income·		N.kr 210 000
Interest on debts:		N.kr 100 000
Total added value.		N.kr 875 000
From this should be deducted:		
'Normal' remuneration for total capital (6% of 1 805 000).	N.kr 108 300	
'Normal' remuneration for labour N.kr 20 per hour × 26 000	N kr 520 000	
		N.kr 628 300
Rent of land:		N kr 246 700

Rent of land is a measurement often used for assessing the value of the land in agriculture and the same measurement may be used in aquaculture.

The value is arrived at by capitalizing the yearly rent of land at a definite capitalization factor. In this case, a factor of 16·7 or at 6% (100/6 – 16.7%) is used to estimate the value of land as: 246 700 × 16·7 – N.kr 4 119 890.

Governments may indirectly influence the rent of land by various measures like regulation of the rate of interest, subsidies on sales prices, or important input factors such as feed, and—finally— by regulation, of the size and layout of an establishment.

Other useful economic indicators calculated in the previous model for economic analysis in aquaculture include: (*i*) Investment calculated per yearly man-hours and per kilogramme produced indicate how capital-intensive that activity is; (*ii*) Production per yearly man-hours measures productivity; (*iii*) Production in kilogrammes per volume or surface unit of water shows how intensively the ponds are used. Whether volume or surface indicators should be used will depend on which species are produced.

The model for economic analysis provides an overview from the point of view of a financial analyst. The analysis is static, however, describing a given situation, and consideration should also be given to some of the variations and interactions of factors influencing the income and variable costs described below.

3.3.1 *Production functions.* Production or product-factor relations show the co-variations between the output and input for different types of production. In aquaculture the studies of these functions are of a biotechnical character.

As feed costs form one of the main cost elements in intensive aquacultural production, numerous studies of

growth (output) in relation to feed (input) have been undertaken. Other examples of these types of relationship are yields or income related to labour or capital, combinations of nutrients in a fertilizer mix, *etc.*

3.3.2 *Factor substitutions* (Factor factor relations). A given production or yield may be reached by different combinations of production factors. The main groups of production factors are natural resources, labour and capital. To a certain degree, these factors may substitute each other to achieve a given level of production.

An example of this relationship is the universal mechanization process which is substituting labour by capital. Another possible substitution in aquaculture is in the feed: water surface or land area relations.

The substitution relations do apply both between production factors and between products. When the production quantity is given, the question is how to produce this quantity with the least possible resources. In terms of values the resources which give the lowest cost per unit produced should be combined and, in practice, the farmer is constantly trying to replace expensive production factors by cheaper ones.

3.3.3 *Product/product relations*. These relations deal with the questions of which types of products are to be produced, and what type of product mix should be chosen. Should salmon or trout be produced, and should fingerlings or consumer fish be reared, *etc*?

The availability of production resources limits production volume in aquaculture. Resources are scarce to varying degrees. Therefore, a choice has to be made between different products that can be produced.

The production can be achieved at a given state of technology and with a given aggregate of resources. Both technology and resources are changing and so are production possibilitites. There are examples which can result or have resulted in expansion and contraction of aquaculture production, *eg.* pollution of fresh water may reduce production, while improved techniques, utilizing marsh lands or swamps, have expanded aquaculture production.

3.3.4 *Economies of scale*. Economies of scale are associated with mass production and large-scale enterprises. In many industrial processes, when all inputs are doubled, we may find that output is more than doubled. This phenomenon is called increasing return to scale.

The most dominant characteristics of economies of scale are the use of a relatively high level of capital and technology per man-year and a low number of working hours per unit produced. Savings or economies of large-scale production only come into full play if there exist possibilities for division of labour and specialization of production.

When planning development of aquaculture, it is important to take into account possible economies of scale both in aquaculture and in competing industries. Depending on the objectives or formulated targets for the development of aquaculture, economies of scale may either be discouraged or encouraged.

The theoretical basis of economic studies in this field is well developed in production theory, and research and study of aquacultural farm records may provide all the necessary data.

The method and procedures used in agriculture can be used in aquaculture as the similarities in the production process are striking.

The techniques of economic analysis have not been discussed in detail, but it is emphasized that there is an urgent need for research into this field to arrive at standard figures of production, with increased use of the separate production factors and tables over substitutable production factors. This will enable both the aquaculturists and the planners to establish more reliable budgets and prognoses, and improve both profitability of the industry and allocation of production resources.

4 Evolutionary aspects of integrated rural development

Development of aquaculture is influenced by four factors which include: (*a*) obstacles to rural economic development; (*b*) sale prices and markets; (*c*) factors influencing real cost in production and marketing; (*d*) policy issues in the promotion of aquaculture.

Throughout the world some common traits of rural economic life can be recognized. These characteristics (section 3.1) are most pronounced in developing countries, but are found in developed countries as well. Some of the obstacles are easily removed and can be handled at a local level; others require long-term adaptation of environment and society.

4.1 *Ownership of natural resources*

The primary natural resources required for aquaculture are water, land, feed and fertilizers. The ownership of these resources may be biased in that only a few people own or control them. This may contribute to an inefficient utilization of resources and to inequality in income distribution in areas where population densities and growth are high. Rivers, lakes and seashore are in many cases common property while land is usually not. In this event, aquaculture could represent an alternative occupational activity for landless rural inhabitants. Some fish farming techniques like the use of floating cages represent such a possibility.

By imposing or initiating different taxes or subsidies on the use of land and water, production quantities can in fact be increased so that marginal production resources become almost as remunerative as those of better quality.

The natural resources can be marginal owing to climatic and topographical conditions, structure of ownership, distance to markets, *etc.* These are all factors that result in different production costs.

The monopolization of land and other resources in one way or another, will greatly influence the level of wages as those without land have no alternative but to offer their services to landlords.

Irrespective of whether an enterprise is large or small, the owner adapts his production quantity in such a way that marginal production cost is equal to the price of the products. Large farmers tend to substitute labour with machinery and thus adopt techniques of production with relatively high land:labour ratios. Small farmers, on the other hand, adopt very labour-intensive techniques.

From the point of view of optimal resource allocation this may be wasteful for two reasons. Firstly, as long as labour is readily available and no alternative occupation exists, its substitution by machinery could be an allocational mistake. Secondly, yields per unit area of water or land tend to increase with decreasing farm size; *ie.* the

smaller the farm, the greater the productivity of land. Conversely, the larger the farm, the greater the average productivity of labour.

In aquaculture, land or water surface area can, to some degree, substitute for feed. In some types of extensive aquaculture, the organisms are not fed at all but are given more than enough space, and live on the biomass produced in the ponds or the sea.

When considering aquaculture in the various parts of the world, it is seen that many patterns are found for ownership and management. In some political systems, collective ownership may be the most common form. In a number of countries, aquaculture is the alternative to agricultural use of the land; in others it will be found that the supply of water in irrigation systems is shared between agriculture and aquaculture. Generally speaking, the pattern of ownership is the same in aquaculture as it is in agriculture. Some enterprises are operated by big land-owners, others are operated by tenant farmers. What should be stressed in this connexion is that established ownership should not be a hindrance to effective utilization of land and water areas suitable for aquaculture. Moreover, well integrated small scale enterprises will often be an important managerial form to further the socio-economic objectives of rural development.

To this end, land reforms and reforms in the traditional pattern of water use may well be some of the most important measures.

4.2 *Problems related to pollution and recirculation*

Aquaculture can be both a polluter and a purifier of the aquatic milieu. Culture of dense fish populations contributes to water pollution through addition of excess feed and fish excrement, and depletion of oxygen, thus making the water less suitable or unusable for many purposes. Conversely, aquaculture itself is very sensitive to many forms of pollution, thus increasing the risk of failure in this industry. On the other hand, aquaculture can be deliberately integrated into plans for purifying water and utilization of resources that otherwise might be wasted.

In addition to evaluating profitability of the separate enterprises, social costs of pollution will most certainly be calculated in future into the production cost. With increasing awareness of the social cost of pollution, the tendency is now for polluting industries to cover the cost of water purification, either by installing their own purifying devices or by paying special taxes.

Successful experiments and operations using sewage water for raising fish have been carried out. In most of these cases the fish have been reduced to meal. Research related to methods for recycling water containing organic matters (wastes) could also provide aquaculture with an alternative source of feed.

4.3 *Education, extension service and research*

The least controversial measure for inducing greater growth of aquaculture is the promotion and support of more research and education. Obviously, human resources are the most valuable assets in any industry. Numerous investigations have provided evidence that improving human resources is the single factor most effective in promoting development.

Only educated people can make full use of technical advances. To become a successful fish farmer, knowledge is needed in biology, technology and business administration. Experience from agriculture is showing a positive correlation between education and innovation, and the same relationship can be expected in aquaculture. Education and extension services should be the link between research units and the aquaculturist; thus, monitoring and introducing new technology, improved production methods, methods for reducing losses (*eg*, disease control), and systems for collection of data and control of operations can be properly co ordinated.

An extension service should also be linked to appropriate authorities who require information to form the basis for regulations and control of, and provide encouragement and incentives to, aquaculture operations.

For the development of rural districts it is essential that research and educational centres are located in the production areas and that basic education and training incorporate flexibility, and make use of existing facilities and resources to the greatest possible extent. As a supplement to research stations, demonstration farms should be established in co-operation with the aquaculturists and the extension service. On these farms, research results from laboratories and stations would be verified through practical tests and the farms may provide a very effective stimulus both to research institutions and to the local technical milieu. Also, demonstration farms are a relatively inexpensive way of collecting and analysing technical and economic data and introducing improvements to aquaculture.

In many countries aquaculture is not of a sufficient magnitude at present to justify separate education and extension services. Administratively these functions are more often placed under the fisheries agencies of governments rather than under the agricultural agencies.

Research programmes for developing aquaculture should be given a high priority and should comprise both bio-, techno- and socio-economic problems.

So far, it seems that priority in the public sector has been given to basic biological research, while technological innovations have, in most cases, come from the industry itself as a result of the need for immediate improvements to farm management.

Socio-economic research has, to a large degree, been neglected, partly because in many countries aquaculture has only recently developed into an industry of any importance. At the same time, gradual transition from rural subsistence economy to commercialized production economy has created socio-economic problems. Basic biological research is well suited for international co-operation, as results and conclusions arrived at are not influenced by local, social and economic disparities.

Co-ordinated research efforts, both on national and international bases, are suggested in order to avoid duplicating effort and to stimulate and improve research.

4.4 *Infrastructure*

In addition to adequate legislation, well developed infrastructures, research and extension services can greatly improve the performance of individual enterprises.

One of the promising aspects of recent rural development efforts is the emphasis on improvement of economic infrastructure for supply of such essentials as domestic water, electricity, waste disposal, roads, *etc*, and such social services as health and general education.

In areas where small fish farmers are effectively organized or where the enterprises are large, many facilities may

be financed by them, but there is reason to believe that in many cases facilities such as fish seed producing units, storage facilities, market installations, *etc*, will have to be provided through government investment and sometimes even operated by government agencies.

4.5 *Liquidity and financial resources*

For both fish farmers and planners it is important to understand the interaction between rentability and liquidity in an aquaculture enterprise. Good rentability and high profits do not necessarily involve good liquidity. To keep the enterprise running, the necessary means of payment have to be provided.

One way to analyse the liquidity situation of the enterprises is to use the historical flow of fund analysis, and look at the balance sheet and the changes in the figures as they occur over a period of time. The asset side of the balance sheet shows the use of the capital, while the liability side shows the course of capital. The use of capital may be to: (*i*) increase current assets, stocks and fixed assets; (*ii*) repay loans and other liabilities; and (*iii*) cover deficit of operation.

The source of capital can be to: (*a*) retain net profits of operations; (*b*) cover depreciation; (*c*) increase loans and other liabilities; and (*d*) reduce assets.

The sum of (*a*) + (*b*) is increasing the owner's capital and is one way of improving the liquidity situation. In addition, liquidity may be improved by measures under (*c*) and (*d*).

The composition of the assets and liability sides should match each other, as investment in durable fixed assets should be financed by long-term loans or equity. Current assets and stock can be financed by short term liabilities.

For lending institutions, the security of their lendings is a special problem in aquaculture because of the risk involved. As it may be difficult to obtain sufficient working capital, the working capital is often wholly or partly financed by an owner's capital.

The working capital in aquaculture should be used for financing: (*a*) stock or raw material, mainly feed, fertilizers and wrapping material; (*b*) stock of fish in production; (*c*) stock of fish in warehouses; and (*d*) claims on customers.

The size of the working capital depends on a number of factors, including: (*a*) *Sales*. The need for working capital will increase by the increase in sales. (*b*) *Seasonal variations*. Large variations in sales will often involve increased need for working capital among other things because of increases in stocks during the year. (*c*) *Profit per unit*. The higher the profit per unit, the lower will be the need for working capital per unit sold. (*d*) *Capital turnover*. Increased capital turnover will, everything else being equal, lead to reduction in the need for working capital. (*e*) *The relationship between fixed assets and current assets*. Increased mechanization leads to a reduction in the need for working capital, while, on the other hand, the need for capital to finance fixed assets will increase.

4.5.1 *The cost of capital*. The main cost item of capital is, of course, the interest paid on loans. The rates of interest are influenced by demand and supply of capital and some rates are subject, in most countries, to government regulations. The time of repayment of loans influences liquidity as long term loans will ease the situation.

4.5.2 *Institutional credit*. As capital is often scarce in rural areas, financing problems and the need for credit schemes will often arise. Such schemes should not only comprise financing of stock of fish and investment in buildings, machinery and equipment, but may also have to be extended to activities such as major engineering works and strengthening of transport systems. How much of this should be financed by individual enterprises and how much should be provided as infrastructure and financed by the authorities will depend a great deal on the social structure of the country and area concerned.

For all the various phases of aquaculture industry, institutional credit is an essential prerequisite. It has been found in agriculture that, so far, large farmers have been the main beneficiaries. A majority of the small farmers have limited or no access to institutional credit, and available supply of credit has been heavily skewed in favour of short-term credit, particularly in the case of small farmers.

These findings in the fields of agriculture will no doubt also be true for aquaculture. It is, therefore, worth paraphrasing from the World Bank Sector Policy Paper the characteristics of condition under which credit is needed and can be used effectively: (*a*) Clear opportunities for economic gain from adoption of new production technology or other improvements; (*b*) Widespread recognition and acceptance of such opportunities on the part of the fish farmer, along with access to training in the necessary skills; (*c*) Delivery systems which provide ready and timely availability of inputs.

For small fish farmers, security is always a problem and some kind of arrangement has to be made to guarantee the loan both for investment and working capital. It should also be accepted that credit administration costs are relatively higher for smaller amounts of credit.

Productivity of the small fish farmer would be considerably enhanced if he could be provided with a comprehensive package of advice and assistance. Institutional credit could replace or augment credit from traditional sources in order to check monopoly situations which cause excessively high interest rates. The farmer could gradually increase his production and market some of his output. The package approach could also include land reform which, if pursued widely, could sharply increase the credit needs of the former tenants who were previously supplied by landlords.

As government development programmes for a given region involve investment schedules, the effect of investment on the income in the region concerned should be taken into account.

Modern income analyses have shown that an increase in net investment will lead to a multiple increase in national income, *ie*, an investment in aquaculture will not only create new jobs in aquaculture. The increased income in aquaculture which the investment entails will be used for demanding goods and services in other sectors of the economy, and there will thus be a secondary expansion of income and production.

It must be assumed that this multiple effect can be significant in rural districts if a large portion of the increased income is re-spent in that particular area, and not put away as savings or transferred to other districts.

There are various ways in which authorities may influence this by encouraging the localization of other enterprises and service institutions in rural rather than in urban areas. Some of the means which would normally be available are: (*a*) tax differentiation by districts; (*b*) localization

control: (*c*) subsidized institutional credit; (*d*) regional transportation support; and (*e*) free extension service.

5 Sale prices and markets

As with the cost of all inputs for production, sale prices of the products have a decisive influence on the economics of aquaculture. Principally there are two ways of improving the profitability of the industry by influencing the sale prices; either the sale prices may be increased or the culturist may obtain a greater share of the final sale prices. These, however, are not always very realistic alternatives, for in most cases there are many small farmers and effective competition, and the individual fish farmer has very limited possibilities of influencing the final market prices. Moreover, the prices of aquacultural products are to a large extent fixed in competition with other fisheries and agricultural products. Pond reared fish are often the same species as fished in inland or coastal waters, or at least the consumer can easily substitute other types of fish products and animal protein for pond fish.

In the markets for aquaculture products there are different reactions to changes in prices; various products have different price-elasticities. For sales organizations and central planning agencies, it is important to have information on elasticities of demand to judge whether the market is fully exploited concerning both the level of prices and the quantities supplied.

For planning purposes, forecast of future prices will be essential and these must be based on a study of long-range changes in sale prices, and a comparison of long range changes in sale prices with changes in the cost of the various factors of production such as labour, feed and fertilizer, *etc.* On this basis, estimates of future changes in profitability and competitiveness of the industry may be made.

Fish products are, to a certain extent, subject to seasonal variations in prices as a result of seasonal variations in supply and demand of these products. The supply of fish farm products can, within limits, be better controlled than fish supplies from the traditional fisheries. On the demand side, consumers can be influenced through consumer education to direct their demand to seasons when the supplies are largest, or taught to increase the demand for these products.

Fish farmers can sell their products through various distribution channels or directly to the consumer. In some areas separate sales organizations for aquaculture products have been formed or fish farmers have joined existing sales organizations in fisheries or in agriculture.

Various forms of both horizontal and vertical integration are used to achieve economies of scale both in primary production, processing and distribution and to control markets and prices. In the case of small-scale enterprises which are often to be preferred in rural development, the creation of horizontally organized sales organizations which can pursue an active market policy may be a means by which to secure adequate control of markets for aquaculture, and thus assist in enlarging and stabilizing incomes at the production level.

5.1 *Vertical and horizontal integration*

Horizontal integration refers to an organizational co-ordination of the activities of two or more firms on the same level, while vertical integration refers to an organizational co-ordination of the activities of two or more firms on different and successive levels. According to the method of integration, it is also possible to distinguish between: (*i*) owner integration; (*ii*) contract integration, and (*iii*) integration through co-operation.

Integration may be initiated by external integrators or by the aquaculturists themselves. External integrators are usually firms in the feed sector, processing firms or special business concerns. The main purpose of integration will in such cases normally be the maximization of profit from invested capital. Integration may, however, also be initiated by the authorities.

Aquaculturists' co operatives may be considered as a special form of vertical integration. The farm may be considered the production centre from which integration is initiated forward toward the market (in the case of member ship in marketing co-operatives) and backward toward raw material for farm supplies (in the case of purchasing co-operatives).

In the case of what may be called co-operative integration, the farmers themselves act as a collective integrator. In such cases, maximization of profit from aquacultural production would be the main goal.

The form of integration in actual practice depends on factors such as magnitude and location of aquaculture enterprises, and existing possibilities of integration within the wider and more general framework of fisheries or agriculture.

As to the supply of inputs as well as the production process itself, aquaculture has many similarities to agriculture, while processing and distribution have much the same characteristics as the traditional fisheries for wild stocks in inland and marine waters.

In areas with well-developed agriculture and fisheries organizations, dispersed geographical location and limited aquaculture activities, the most advantageous arrangement for aquaculture may often be to integrate backward to agriculture and, forward, toward the markets through fisheries organizations.

Short geographical distances between enterprises, greater magnitude of the industry, and poor possibilities for integration with other industries are factors which will normally promote integration through the formation of special purchasing and sales organizations within aquaculture. Both of these organizational forms can be found at the same time in a region.

By integrating aquaculture into other rural development projects, both aquaculture and other rural activities could benefit. The advantages to the aquaculture industry may be listed as: (*a*) Opportunities to provide economies of scale; (*b*) Co-ordination of successive production processes; (*c*) Risk reduction and stabilization of income, since the income opportunities are extended to several commodity markets and the margins at each stage of production and distribution go to the integrator; (*d*) Stable supply of raw materials; (*e*) Better opportunity for changing production methods and maintaining control over the quality of raw materials; (*f*) Opportunity of securing a market for final products; (*g*) Better possibilities of obtaining capital.

It should also be pointed out that the kind of economic integration which will be supported and sometimes even promoted by the authorities will have to be decided in an evaluation of the proper balance required between economic and social components of the rural development programme.

5.2 *Price support programmes*

The supply of fish will normally increase with rising prices, as production in marginal enterprises will then become profitable. This increase in production may, however, be upset by a corresponding reduction in the quantity produced by those enterprises which enjoy more favourable conditions for production. With higher fish prices these enterprises may obtain the same profit with less production. In order to secure the same profitability in enterprises with different natural conditions and at the same time keep aggregate production at a relatively high level, measures must be taken to influence profitability in the enterprises. Production in marginal enterprises may be stimulated with price subsidies, credits on reasonable terms, extension service, *etc.*

It should be clear from the above that the quantity produced is influenced both by sale prices of the product and by the cost of production. It must be emphasized, however, that when production expands rapidly, quality may decline and thus tend to reduce the prices and endanger profitability. Therefore it is important to take into account the level of prices when major changes in production are planned.

The main specific measures used to influence profitability and production volume could be: (*a*) Regulation and establishment of control of production volume at each farm; (*b*) Direct monetary support in the form of subsidies and various forms of grants; (*c*) Purchase-loan storage programmes to guarantee or support prices; (*d*) Purchase and-resale differential subsidy plans; (*e*) Programmes that aim to influence the demand for aquacultural products or influence the real cost of production.

None of these programmes except (*e*) are to be recommended in terms of effective long term resource allocation. In (*a*) the consumers suffer through a scarcity of goods and higher prices as production volume is restricted. In (*c*) the government is creating additional demand to support prices. The quantity bought by the government may either be exported at dumping prices, or be destroyed or stored. In (*d*) the government lets the price fall to a low level and pays the difference between the market price and the desired support price. In this case the consumers are ensured supplies at a low market price and the aquaculturist is ensured relatively high income.

The different measures described all have different influences on prices and production quantities, but do not contribute to reduction of the real cost of production. In the broadest sense, reduction of real cost of production is the only possible way to increase real income *per caput*.

Fish is a perishable product and one of the main problems in fish marketing will be the highly fragmented nature of the market and, connected with it, uncertainty about fish prices and regular availability of fish for consumption. In any attempt to increase productivity, therefore, efforts must also be made to improve marketing systems and pricing policies. In the absence of an appropriate and timely emphasis on the development of markets, intensification of production may lead to difficulties in the disposal of marketable surpluses.

6 Factors influencing real cost in primary production and marketing

6.1 *Productivity and employment*

The productivity of aquaculture is important both to the individual farmer and to the national economy. For the individual farmer, productivity is the foundation that can provide him with a reasonable standard of living, and for the nation, productivity is the basis for ensuring the consumer food products at reasonable prices. The individual farmer, his organization and the government can, by different means, influence the productivity of the industry. But how should this be reconciled with the fact that in many developing countries unskilled labour is, generally speaking, the only production factor in abundant supply in rural areas, while capital, foreign exchange, skilled labour and managerial ability are in short supply? The most suitable industries for establishment in such conditions are those that maximize total output and use these scarce factors in combination with as much unskilled labour as possible; one of the main purposes of rural development is to create employment and reduce the drift of unemployed people to urban slums.

As use of capital in the form of technology is improving productivity but reducing employment, the productivity objective and the employment objective in aquaculture may easily become irreconcilable. High productivity often means fewer working hours per unit produced and, accordingly, fewer persons are employed. In fish farms of a given size, measures taken to improve the yield per unit area or volume of water (*ie*, more intensive production) are preferable. These measures increase the income and profitability without reducing the need for labour. However, the greatest impact on the labour market will be created by the expansion of old farms and the establishment of new ones.

In developed countries the situation is often different. After the second world war, labour has become the limiting factor and, with increasing competition for labour, great prominence has been given to wage paying ability per working hour. For the individual small-scale fish farmer who includes his labour in the operation, this measurement is of particular interest. Where alternatives to fish farming are available, he will tend to choose that occupation which gives him the largest total income. Hence, fish farming will

TABLE 1

AVERAGE COST OF WAGES, INTEREST AND DEPRECIATION IN ENTERPRISES WITH PRODUCTION ABOVE AND BELOW 15 TONS PER EMPLOYEE PER YEAR IN NORWAY, 1971

Production category	*Total production per enterprise* (*kg*)	*Total production per employee* (*kg*)	*Labour cost per kg produced* (*N.kr/kg*)	*Interest and depreciation per kg produced* (*N.kr/kg*)	*Total interest, depreciation and labour cost per kg produced* (*N.kr/kg*)
Above 15 tons	38 555	13 900	1·80	2·21	4 01
Below 15 tons	6 657	6 550	3 81	1 70	5·51
	+31 898	+7 350	−1 99	+0 51	1·50

only be carried out if it is at least as remunerative as any other rural occupation.

6.2 *Size of enterprise and type of production*

In aquaculture it must be assumed that the size of the enterprise does influence cost of production. Thus total unit cost diminishes with increase in size, mainly due to higher productivity (ie, quantity of product per employee), while fixed costs such as interest and depreciation tend to increase with the size of the enterprise. This is illustrated in Table I.

It should be noted that the table does not show the total production cost per unit. In order to arrive at this, variable costs, such as feed and stocking material, must be added. These costs are in the main changing proportionally with the quantity produced, and the size of the enterprise has little or no influence on unit costs. (Apart from the fact that larger enterprises can often obtain reduction in feeding costs in the form of quantity rebates on prices.)

Enterprises in which the fixed costs constitute a relatively large part of the cost are more vulnerable to a decrease in prices and especially to a decrease in the utilization of capacity. Changes in technology may also make production equipment obsolete, as illustrated by the introduction of floating cages in the beginning of the 1970s, which in many cases involved a switch of production away from raceways on shore, where expensive pumping installations had often been constructed.

For rural development, the question of capital-intensive versus labour-intensive aquaculture is of decisive importance, for to some degree capital and labour may substitute each other. If, therefore, a given quantity is produced in a few large enterprises, fewer people are employed than would be the case if the same quantity was produced in many small enterprises.

In a free market the balance between capital-intensive and labour-intensive techniques is indirectly a question of the cost of both labour and capital, as expressed in production cost per unit. High wages and low rate of interest contribute to the substitution of labour by capital and vice versa.

In rural districts where labour is abundant and relatively cheap, enterprises are tending to become labour-intensive. Conversely, investment in labour-saving equipment and facilities may often improve the productivity of an enterprise.

Complex production techniques usually favour larger-sized enterprises. In aquaculture the complexity of production may be defined with regard to the: (*a*) steps in primary production and processing; (*b*) types of fish species produced; (*c*) degree of integration with other types of production; and (*d*) production technique and level of technology.

An example of a simple type of aquaculture production operation is the rearing of rainbow trout in floating cages from fingerlings to consumer size fish. At the other extreme are the more complex production enterprises undertaking the entire operation from rearing brood stock to production of consumer size fish. Some types of production techniques require relatively large investment in order to develop water resources. The enterprise must be of a certain magnitude if the investment is to be economically justified. In many cases, fencing off coastal sounds or enclosing a portion of a tidal flat requires capital resources far beyond those available to a single 'ordinary' fish farmer. As an example, the cost of fencing off a sound (50 000 m^3 of water) with an estimated total carrying capacity of 150 000 kg salmon (*Salmo salar*) in Norway amounted to US$ 125 000 in 1970.

Transportation costs of both inputs and outputs limit the size of a farm. In particular, transportation costs of fingerlings and large quantities of perishable feed like trash fish may be expensive. For a well run trout or salmon farm in western Europe, about 15 000 kg of dry feed per year is required for a profitable operation. If the fish farm is mainly using trash fish as feed, some 90 000 kg is needed at a feed conversion ratio of 6:1. As a consequence the transportation cost of the feed per kilogramme will increase by six times and will be reflected in the price of marketable fish.

6.3 *Intensity of production*

In aquaculture several yardsticks are used to measure intensity of production. The most common ones are: (*a*) annual yield in kilogrammes per cubic metre of water; (*b*) annual yield in kilogrammes per hectare of water surface; (*c*) annual production in kilogrammes per employee per year; (*d*) annual yield in kilogrammes per feeding unit or feed conversion ratio; and (*e*) investment per kilogramme of fish produced per year.

It must be stressed that these yardsticks hardly give any information about the profitability of the enterprise as they only indicate one of the many factors which determine the income of the enterprise, and do not take costs into account.

In many fish culture operations, feed costs constitute a major cost item ranging from 40–60% of total cost. Improvement of the feed conversion ratio will largely contribute to reducing feed costs. This can be accomplished mainly through better feeding practices, including less feed wastage, more suitable types of feed, and improvement of the fish strains for this purpose.

The feed conversion ratios in fish culture compare well with other types of high quality protein production (Møller, 1973). Thus fish utilize their feed more effectively than in the case of pigs. While about 4·5 feed units per kilogramme (approximately 7 400 kg cal) is needed for the production of 1 kg of pork, only about 2 feed units are needed for the production of 1 kg of fish. Some selected fishes compare favourably with pork with regard to nutrient content (Table II).

TABLE II

NUTRIENTS IN THE EDIBLE PORTION OF ONE POUND (0 454 kg) OF PORK AS COMPARED WITH THOSE IN THE SAME QUANTITY OF FLESH IN SELECTED AQUACULTURE SPECIES

Food Source	*Protein (per cent)*	*Fat (per cent)*
Medium fat pork (carcasses)	8	41
Milkfish	20	2
Oyster	10	4
Carp	22	9

Throughout the world, polyculture and crop rotation are commonly used to increase the yield both with respect to yield per unit surface area, per employee and per unit of input such as feed and fertilizer.

Successful polyculture of carps and ducks is carried out in many east European countries. The beneficial effect of fish on rice has been observed in various countries. In Indonesia (Schuster and Kesteven, 1954), observations show that in all cases the yield of rice was increased by such practice. The average rice production rate was 48·73 kg per 100 m^2 in fields without fish, and 51·74 kg or 6·2% more in fields with fish.

From China and Malaysia it is reported that by rearing fish in rice fields, yields of rice alone have increased by 10 - 15%.

Within some additional variable costs, the practice of polyculture gives higher yield and accordingly higher revenues for the same volume of water. These costs are mainly labour, feed and fertilizers. Then fixed cost of polyculture may be the same as for a monoculture. However, whether polyculture or any other changes in production practice will lead to increased profit for the individual fish farmer depends on whether the additional income is greater than the additional cost, irrespective of whether it is fixed or variable cost.

Four general forms of aquaculture are enumerated by Idyll (1973): (*i*) Rearing of fish and other animals in hatcheries for release into the sea or lakes with the expectation that natural stocks will be supplemented and commercial or angling catches be improved. (*ii*) The capture and confinement of the young. They may be left in enclosures to feed for themselves, the water may be fertilized to encourage the production of natural food, or supplementary feed may be supplied. (*iii*) The raising of young fish from eggs obtained from wild parents, and their retention and feeding in enclosures until they reach marketable size. (*iv*) The most sophisticated method which involves the hatching of eggs, raising of young in ponds or other enclosures until they reach marketable size, and the maintenance of brood stock.

In sea ranching, which may be considered a special form of aquaculture, part of the life cycle of the fish (usually the early delicate stages) is spent in a controlled environment. The rest of the life (usually the growth phase) is spent in natural environments in the open sea or in lakes. At present sea ranching is considered primarily for salmonid species. The main benefit obtained by this practice is enlarging the base of the protein source for feed, as the fish utilize naturally occurring food organisms. However, from the point of view of economics, the questions must be asked whether this extensive type of production is or can be profitable, who is to carry the cost of stocking, and how costs are to be recovered.

The main economic factors influencing sea ranching as compared to fish farming are that in the latter case feed costs are high, while in the former, additional stocking and harvesting costs are incurred. Moreover, predators create greater problems in sea ranching than in regular fish farming. The profitability of sea ranching is dependent on the interaction of the following factors:

Cost side	*Income side*
Production cost per fish stocked	Average weight of fish recaptured
Number of fish released	Number of fish recaptured
Harvesting cost	Market price of catch

Large fingerlings are more expensive to produce than smaller ones, but as a rule the percentage recaptured does increase with the size of the fingerlings released. Thus the intensity of fishing and harvesting cost are reduced to achieve a given catch. The time from release until harvesting influences both the average weight per fish and the number of fish recaptured. Increased duration of time from the release of fingerlings to time of recapture will increase the average weight per fish but reduce the number caught.

6.4 *Risks*

The risk in aquaculture is substantially greater than in any other form of animal husbandry, mainly due to the fact that production takes place in water, an environment which is relatively little known and difficult to control by man. As is always the case in ventures with great uncertainty, profits must usually be larger than in enterprises where that risk is lower, as recovery of the risk has to be stipulated as part of the profits. Low profit enterprises in a risky business are especially subject to failure.

The financial structure of the enterprise may reflect a lesser or greater degree of risk as expressed in the figures showing the solidity of the enterprise (a solidity measure is the percentage of equity in relation to total capital of the enterprise).

Price risk represented by price fluctuations must be expected in aquaculture. Seasonal price fluctuations may, however, be overcome to a certain extent either by with holding supplies or by increasing the price, amount of product stored, and future supply, or by reduction in future prices.

Claims on customers and advances to suppliers may be considered as sundry risks, but the main risk in aquaculture arises during the production process. These risks may be classified as technological, biological, physical or socio-economic.

The normal losses resulting from biological and physical conditions in aquaculture are quite high. In trout culture, an investigation in Norway showed that diseases were the most frequent reason for losses (see Table III).

TABLE III
REASONS FOR LOSSES IN SOME NORWEGIAN TROUT CULTURE ENTERPRISES IN 1970

Cause of loss	*Percentage of total losses*
Disease	28
Climatic conditions	19
Faulty construction	16
Pollution	9
Failure of water supply	9
Employee error	7
Predation	5
Transport	5
Silting	2
Total	100

As fish stock in aquaculture may represent values equal to the total yearly sale, it is especially important for small-scale operators to be able to safeguard against losses. Insurance is a way of spreading risk, but insurance of fish stocks in aquaculture is rather expensive because of the high frequency of losses, and the difficulties in assessing the risk involved and tracing and assessing the source of losses. In many countries the aquaculture industry does not have sufficient dimensions to provide a market for insurance, and the absence of possibilities for insuring the stocks often constitutes a serious obstacle to the development of aquaculture.

One way of overcoming this problem and limiting the risk of the owner's capital is to form companies, *eg*, joint stock company or limited partnership with limited liabilities. Also, special tax regulations may influence the risk of a company to some degree. The operating income of an enterprise consists of cash and credit sales, plus increases or minus decreases in stock. But the basis for taxation may be stipulated in another way, and so reduce the risk of the

enterprise. For example, consider that: (*a*) = cash sales + accounts receivable paid, (*b*) = cash sales + credit sales, (*c*) = cash sales+credit sales + increases/decreases in stock. Most aquaculturists will certainly prefer the first alternative as in this case no income is taxed until it is paid by the customers. Alternatives (*b*) and (*c*) may have the effect of forcing fish farmers to pay taxes two to three years before any cash flows are generated. Another equally important point which must be made with regard to taxation systems is that as aquaculture income may fluctuate considerably from year to year, and as income taxes in most countries are progressive, it would be an advantage to the industry if an average tax assessment could be introduced.

7 Policy issues in the promotion of aquaculture

7.1 *Government responsibilities and programmes*

The kind and amount of assistance which governments provide or should provide for the development of aquaculture depends on the size of the target population in the area, the stage of development already achieved, the relationship with other sectors, and the skill and the physical, human and financial resources that can be mustered to help population groups which are severely disadvantaged.

A large variety of situations can be envisaged. Economic and skill resources may or may not be adequate for working out a solution. It will probably be found in a majority of cases that the first step to be taken is to provide a survey of the natural resources, *ie*, land and water areas which might be utilized, the quality and productivity of the waters, and biology and pathology of species which lend themselves to cultivation in the environments concerned. The next step would be to make a diagnosis of the socio economics involved in establishing aquaculture. On this basis, the kind and amount of national or international assistance required may be determined.

The obligations of governments with regard to this were aptly pointed out by the United Nations World Food Conference in 1974: 'The main needs in the field of aquaculture are for increased government support in the form of grants, loans and subsidized interest rates and similar incentives, as well as an increase in the number of qualified extension workers . . . it is likely that continued growth in world fisheries production will by the end of the century be dependent to a substantial degree on increases in output from aquaculture'.

7.2 *Organizational and statutory arrangements*

It is increasingly recognized that human resources are the most precious resources the developing countries have, and that, therefore, the key element in rural development is the involvement of the people in the target group: the underprivileged and the poorest. It is, as pointed out by the 1974 World Food Conference, '. . . a very complex long-term process entailing changes in patterns of ownership, political power structure, social traditions and attitudes, the organization of economic activity and the institutional and administrative set-up of each society'.

Too often rural people are not aware of the possibilities which exist or are unable to take advantage of them, and to bridge this gap is a major responsibility of the authorities concerned. It needs to be stressed here that the concept of integrated rural development requires a fundamental review of policies and approaches for socio-economic progress in the rural sector.

In many developed as well as developing countries, statutory arrangements have played an important part in development. There is no doubt, however, that government initiative and activities must be expanded and accelerated. In this process, aquaculture cannot and should not be entirely separated from agriculture and fisheries, and there is often no reason to make special arrangement for the aquaculture sector. These can often be provided as an adjunct to other activities in the fields of research, extension service, financing, marketing, *etc*. To provide these services in time is, however, a major responsibility of governments.

Intensive research has revealed that degrees of sustained economic development are most closely associated with improvement in the effectiveness of financial institutions. It has been found for Africa, and is probably true for other regions as well, that very little of the institutional agricultural credit has been directed toward development of smallholder subsistence farming. It is to be hoped, however, that aquaculture development may benefit from the general trend toward more democratic credit schemes. One of the many problems awaiting a solution is to channel financial resources to the small-scale fish farmer engaged primarily in the production of subsistence fish supplies.

The agrarian structure and the need for tenural reform is a major concern in many countries' agriculture development. Thus it has been concluded (Asian Development Bank, 1969) that 'the early upward thrust in agriculture is likely to be blunted or even aborted if the social and legal institutions surrounding rights in land are not altered or reformed'. This no doubt also holds true for aquaculture, although this industry has the benefit of being able to utilize wasteland of little or no value.

It has been pointed out in preceding sections that research and provision of education and extension services are activities which are essential to aquaculture. What should be underlined here is the need for specialized skill and specialized research and demonstration units. This will mean restructuring and upgrading the advisory agencies so that they may carry new knowledge to the fish culturists.

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Aspectos Jurídicos, Sociales y Ecónomicos de la Acuicultura

R. Ramírez Granados

Extracto
La acuicultura, como técnica biológica destinada a dirigir la produccion de organismos útiles en el agua, está llegando a una etapa de consolida ción para colocarla en igualdad de condiciones con la agricultura y la ganaderia. Del punto de vista socio económico, esta rama de la economia tiene importancia secundaria en paises desarrollados frente a la pesca deportiva (EE.UU.) o la pesca de gran valor comercial (Japón) En los paises en vias de desarrollo la acuicultura tiene importancia económica y social puesto que ofrece, a un gran número de personas, trabajo, alimento o ingresos mediante inversiones moderadas.

Muchas de las especies (nativas y/o introducidas) se cultivan apli cando procedimientos tecnologicos con patrones varios conocidos, basados en experiencias (propias y/o de otros paises) a veces con excelentes resultados (máximos rendimientos por hectárea por año). El cultivo de ciertas especies no se inició puesto que las existencias naturales son aún más abundantes y la producción cultivada no podria competir en los precios En todo caso los estudios económicos, que demuestran redituabilidad de la acuicultura, son la condición indispensable para su desarrollo Hay muy pocos paises que aprovechan la integración horizontal, de la acuicultura y debian dar más atención a la integración vertical o sea a las operaciones que abarcan el cultivo hasta la forma más avanzada de la comercialización (exportación)

La tenencia y el uso del agua y de las tierras es otro aspecto que implica problemas politicos, sociales y económicos. Por la competición de actividades en acuicultura con otras agropecuarias se crean a veces fricciones de gravedad, sin embargo, estas pueden solucionarse mediante un uso múltiple racional

En todo el mundo la acuicultura afronta serios problemas con la contaminación acuática asi como con la propagación de plagas y enfermedades que afectan las especies cultivadas y al hombre. Mediante una reglamentación internacional, acuerdos bilaterales y/o internacionales se podria auspiciar y divulgar la acuicultura, impedir el deterioro de las propiedades del agua, controlar la introducción de plagas y enferme dades. En el ámbito nacional será indispensable dictar reglamentos precisos sobre el uso de tierras y el agua en cada país según su sistema politico y el desarrollo socio económico

Legal, social and economic aspects of aquaculture

Abstract
Aquaculture as a biological technique oriented towards the production of useful aquatic organisms, is reaching a stage of consolidation which will place it on an equal footing with agriculture and animal husbandry. From a socio-economic point of view, however, this branch of economy is of secondary importance in developed countries compared with recreational fishing (USA) and fishing of high commercial value (Japan) In developing countries, aquaculture is of social and economic impor tance since, with a moderate investment, it offers work, food and income to a large number of people.

Many of the species (native and/or introduced) are cultivated by applying technological procedures to various known stocks, based on the experience of the country concerned and/or that of other countries, sometimes with excellent results (maximum yields per ha per year) The culture of certain species has not started because there are still abundant natural stocks and aquaculture production could not compete at present prices. In any case, economic studies which show the production capacity of aquaculture are an indispensable condition for its develop ment. There are few countries which develop a horizontal integration of aquaculture and more attention should be given to vertical integration, that is, to operations which cover culture up to the most advanced form of marketing (export).

Water and land tenure and use is another aspect which involves political, social and economic problems. Competition between aquacul ture and other agricultural activities sometimes gives rise to serious friction; however, this situation can be solved by rational multiple use

Aquaculture throughout the world faces serious problems because of water pollution and the dissemination of pests and diseases of the cultured species and of man.

Through international regulations and bilateral and/or international agreements, aquaculture could be fostered and popularized, deteriora tion of the properties of water prevented, and the introduction of pests and diseases controlled. It will also be indispensable to adopt exact regulations governing the use of land and water in each country accord ing to its political system and socio economic development.

Aspects juridiques, sociaux et économiques de l'aquaculture

Résumé
L'aquaculture, technique biologique destinée à aménager la production des organismes utiles dans l'eau, atteint un degré de consolidation qui la situe sur le même plan que l'agriculture et l'élevage. Si, dans les pays développés, cette branche d'activité joue un rôle secondaire du point de vue socio économique par rapport à la pêche sportive (Etats-Unis) ou a la pêche d'intérêt commercial (Japon), dans les pays en voie de développement, elle est importante, tant au plan économique que social, car elle offre à un grand nombre de personnes un emploi, de la nourriture et des revenus en échange d'investissements modérés.

Une bonne partie des espèces (qu'elles soient natives ou introduites) s'élèvent selon des procédés techniques dont le mode varie sur la base de l'expérience acquise (qu'elle soit originale ou provienne d'autres pays) parfois avec d'excellents résultats (rendement maximal par hectare par an). La pisciculture se détourne de certaines espèces lorsque les ressources naturelles existantes sont trop abondantes, ou lorsque la produc tion de l'élevage ne serait pas concurrentielle sur le plan des prix. Dans tous les cas, des études économiques démontrant la rentabilité de l'aquaculture sont la condition indispensable de son développement. Peu de pays tirent parti de l'intégration horizontale, et l'on devrait accorder une plus grande attention à l'intégration verticale, c'est à-dire aux opérations qui englobent l'élevage tout entier jusqu'aux formes les plus avancées de la commercialisation (exportation).

Le mode de propriété et l'usage des eaux et des terres est un autre aspect de la question qui pose des problèmes politiques, sociaux et économiques.

La concurrence entre les activités aquicoles et d'autres modes d'exploitation donne parfois naissance à de graves conflits, qui peuvent néanmoins trouver des solutions en termes de complémentarité ou de simultanéité (usages multiples)

Dans le monde entier, l'aquaculture se heurte aux graves problèmes imputables a la contamination des eaux, ainsi qu'à la propagation des maladies et des infestations qui s'attaquent aux espèces d'élevage. Grâce a une règlementation internationale et à des accords bilatéraux ou internationaux, il devrait être possible de favoriser et de vulgariser cette activité, de prévenir la détérioration de la qualité de l'eau, de lutter contre la propagation des infestations et des maladies Dans le cadre national, il est indispensable d'adopter des règlements rigoureux to uchant l'utilisation des terres et des eaux, conformément au système politique et au développement socio-économique de chaque pays

1 Introducción

La acuicultura como técnica biológica dirigida a producir en el agua organismos útiles, está llegando a una etapa de consolidación que la colocará a la par de la agricultura y ganadería, como actividad tendiente a dirigir y racionalizar la explotación de los recursos acuáticos y proporcionar alimento y trabajo a millones de personas.

Las extensiones acuáticas del mundo experimentan el severo impacto del desarrollo industrial, agrícola y urbano, que pone en peligro la producción y el uso recreativo de las aguas. De antemano puede asegurarse que la contaminación incontrolada puede anular los logros de la acuicultura, pero también en el cultivo acuícola descansa la posibilidad de restablecer lo destruido.

En virtud del importante papel que desempeñan las extensiones acuáticas, como fuentes de alimento, trabajo y diferentes recursos, cabe implementar su protección con instrumentos jurídicos que conduzcan a la integración vertical y horizontal de la acuicultura en beneficio de la creciente población mundial y en especial de los habitantes subalimentados de las naciones en desarrollo.

Las disposiciones jurídicas de carácter nacional deben contemplar el empleo múltiple del agua, adoptando una política equilibrada que otorgue prioridad a los usos más necesarios y productivos. Es indispensable también contar con leyes y acuerdos de vigencia internacional para evitar al máximo la contaminación de las aguas y la dispersión de enfermedades y plagas que afectan a los cultivos acuáticos o al hombre.

Especialistas en diversas partes del mundo opinan que la contribución de la acuicultura a la alimentación humana es y seguirá siendo limitada hasta tanto se disponga de reser vas naturales que puedan ser explotadas a gran escala en

forma continua. Ellos argumentan que los numerosos intentos de repoblación efectuados para rehabilitar especies marinas han tenido resultados muy limitados o nulos. Pasan por alto el hecho esencial de que en dichos experimentos no se ejerció control sobre un ambiente acuático tan variable como el mar y olvidan también los informes técnicos reveladores de resultados positivos.

La acuicultura, además, es una técnica biológica que debe llevarse a cabo preferentemente en ambientes controlados o semi controlados. El éxito económico depende del grado de control sobre el ambiente acuático. Buen ejemplo de ello son los cultivos intensivos de diferentes especies en ambientes confinados.

En consecuencia, cabe esperar la participación creciente de la acuicultura en la alimentación humana, en la medida que se controle el ambiente acuático, a la manera de los países con tecnología más avanzada y de aquellos cuyas experiencias los han llevado a la obtención de grandes rendimientos.

2 Significación socio-económica de la acuicultura

En los países industrializados la acuicultura destinada a la alimentación tiene importancia secundaria frente a la producción de especies como por ejemplo la pesca deportiva (EE.UU.) o de gran valor comercial (Japón, Francia, etc.), aunque esta situación tiende a cambiar a medida que se cuantifican las necesidades futuras. En los países subdesarrollados o en vías de desarrollo, la importancia económica y social de la acuicultura radica en la posibilidad de producir alimento y dar trabajo e ingresos a gran número de personas mediante inversiones moderadas.

Hay ejemplos significativos de cómo la captura de especies introducidas a bajo costo en depósitos artificiales, ha transformado la economía cerrada, de subsistencia observada en centros de población marginados, en economía de consumo. De ahí la necesidad de realizar estudios económicos de preinversión que demuestren la redituabilidad de la acuicultura, pues de ello depende el valor social de los proyectos. La condición indispensable para el desarrollo vigoroso de la acuicultura es lograr que sean redituables las inversiones en trabajo y recursos financieros y pueda así crearse y distribuirse riqueza como medio de lograr el mejoramiento social que se persigue. Si un proyecto económico no es productivo o redituable carece de significación social ya que ésta depende de la distribución equitativa de las utilidades generadas.

Las formas de propiedad agraria y uso del agua difieren considerablemente de país a país de acuerdo con el sistema político y económico.

Aunque los factores mencionados influyeron en el progreso y el desarrollo relativo de la acuicultura, el factor decisivo parece haber sido la necesidad humana de alimentos. No es sorprendente por eso su gran desarrollo en los países asiáticos, desde tiempos remotos y bajo diferentes sistemas de tenencia y grados de desarrollo. Modernamente, se observa algo semejante a escala mundial, pues al lado de países que aplican una tecnología muy avanzada al cultivo de las especies de alto valor comercial, existen otros que aplican procedimientos basados en experiencias que, sin embargo, producen excelentes rendimientos.

Los pueblos de los diversos continentes siguen patrones muy variados en el desarrollo de la acuicultura adecuados a las condiciones naturales y económicas de la región. Generalmente se dedican primero al estudio y uso de las especies nativas y después, a las que han sido cultivadas tradicionalmente en diversas regiones del mundo. Estas se seleccionan según el caso y el uso particular a que estén destinadas.

Regularmente la acuicultura no se encuentra integrada según la región, país, especie y objetivos que en cada caso se persiguen. En cuanto a integración horizontal hay muy pocos países que aprovechan al máximo los recursos hidrológicos (depósitos naturales y artificiales, lagunas costeras, etc.) disponibles para la acuicultura, pues carecen de una política general para lograr el uso múltiple del agua. Lo mismo puede decirse de las numerosas especies potencialmente cultivables, de las cuales se aprovecha un porcentaje mínimo. La integración vertical, referida al grado de tecnificación alcanzado en los cultivos y a su transformación paulatina de extensivos a intensivos, debe comprenderse también, desde el punto de vista económico, como la operación que abarca el cultivo, y la forma más avanzada de comercialización, que es la exportación. Las cuantiosas exportaciones de truchas cultivadas por Japón y Dinamarca muestran la importancia que la acuicultura puede tener para el comercio exterior.

De igual manera el Japón exporta la 'semilla' de ostión hacia los EE.UU. e importa a su vez anguilas juveniles para completar su crianza hasta la talla comercial. Existe también tendencia a modificar el cultivo de especies que alcanzan precios elevados por aquellas con las cuales se obtiene una producción masiva de proteínas a bajo costo. Esta tendencia se observa incluso en los EE.UU. en donde tradicionalmente se ha rechazado el cultivo de especies como las carpas y algunos catostómidos. De esta manera los países se preparan a afrontar una probable crisis alimentaria general en el futuro.

Para que la acuicultura cumpla con sus finalidades de carácter social, desde los proyectos muy elementales a nivel familiar hasta los esquemas comerciales más elaborados (los cultivos de camarón, madreperla, ostras o peces) deben producir utilidades y no sólo medios de subsistencia. Por esa razón las investigaciones económicas deben recibir más atención, especialmente en el análisis de costos y precios, unidas a los aspectos biológicos que más influyen sobre la redituabilidad de los proyectos como velocidad de crecimiento, densidad de siembra, mortalidad, conversión de alimentos y muchas otras variables.

Los cultivos que han alcanzado mayor relevancia son los de especies comestibles y algunos de uso suntuario como las perlas, pero abarcan ya a numerosas especies de diversos grupos de animales y vegetales. Las carpas, truchas, 'bangos' (*Chanos chanos*), tilapias y bagres entre los peces, las ostras y abulones entre los moluscos y los camarones entre los crustáceos, son objeto de gran demanda comercial y por ello han dado lugar a numerosas observaciones e investigaciones que han conducido al cultivo. Existe ya abundante bibliografía acerca de los aspectos tecnológicos y económicos importantes en el cultivo de dichas especies.

Los logros económicos fundamentan y abarcan los objetivos sociales de la acuicultura, ya que el hombre, además de comer, necesita comerciar para adquirir los bienes de uso e indispensables para la producción. La acuicultura ha demostrado su importancia económica bajo las variadas circunstancias creadas en países de diferente régimen político y grado de desarrollo. En tanto que los países altamente desarrollados concentran su atención en el cultivo de especies de alto valor económico, bien sea por su

valor alimenticio o deportivo, los países en desarrollo dan prioridad generalmente a las especies de mayor rendimiento por hectárea y por año. En este último caso, la acuicultura intensiva es precedida por períodos a veces prolongados de acuicultura extensiva que se practica en depósitos naturales o artificiales mediante la combinación empírica de varias especies. La etapa intensiva sobreviene cuando se justifica económicamente. Esto sucede cuando la demanda supera a la oferta y origina precios suficientemente atractivos para que se inicie el cultivo comercial.

En Noruega funciona desde 1969 una instalación para la cría comercial de salmón del Atlántico. Se inició con capacidad para producir de 500 a 600 toneladas anuales y ha alcanzado las 1 500 toneladas con valor de $EE.UU. 4.5 millones. El Reino Unido fomenta el cultivo de los peces marinos más redituables, sobre todo los peces planos (lenguados, rodaballos y platijas).

Los cultivos de ostras en Francia producen anualmente más de $EE.UU. 2 millones. El Japón realiza grandes inversiones para incrementar los cultivos de langostas, y jureles (*Carangidae*).

El cultivo de ciertas especies no se inicia puesto que las existencias naturales son aún abundantes y la producción cultivada no podría competir en los precios.

La tecnología de los cultivos deberá estar precedida, al menos, por suficientes observaciones pero preferentemente, por datos derivados de la experimentación científica con un plazo y una costa realización. Cuando la acuicultura se practica con finalidades exclusivamente comerciales, deberán tomarse en cuenta dichas circunstancias y las que se indican a continuación.

La acuicultura compite desde el punto de vista económico no sólo con la pesca comercial, sino también con algunas actividades agropecuarias. En ocasiones las 3 actividades son complementarias y pueden practicarse simultáneamente. A veces se escoge la alternativa de practicar una sola de ellas. En tales casos debe tomarse la decisión basada en el estudio comparativo de los beneficios sociales, costos de producción, utilidades y aprovechamiento óptimo de los recursos naturales, según el uso de la tierra y el agua.

En relación con lo anterior debe recordarse que hay extensiones pantanosas, barrancos y áreas que por muchas razones son inútiles para la ganadería o la agricultura, pero en cambio pueden ser aprovechadas por la acuicultura mediante obras de bajo costo. Persiste sin embargo la tendencia a desecar pantanos para dedicarlos a la ganadería o bien a la agricultura, creando fricciones sociales de gravedad.

También la gran demanda de agua de las actividades industriales y los efectos contaminantes de los desechos, contribuyen a limitar la expansión de la acuicultura y a complicar los problemas sociales.

Sin embargo, hay actividades económicas que influyen sobre el desarrollo de la acuicultura mediante modificaciones favorables en el medio acuático, como por ejemplo, la retención de agua con represas que originan extensos embalses y la construcción de sistemas de canales, que mantienen comunicadas a las lagunas costeras con el mar. La erección de tales presas afecta a especies migratorias de importancia, aunque este daño se repara mediante la construcción de pasos y escaleras para peces.

Otros efectos derivados del desarrollo económico son diversas formas de contaminación, sobre todo cuando ocurren en países carentes de los medios económicos y tecnológicos necesarios para su control. En estos casos la acuicultura llega al rescate de la riqueza natural perdida: la liberación de grandes números de alevines de diversas especies ha mantenido la riqueza pesquera en áreas muy afectadas como los Grandes Lagos. Los daños económicos por este concepto suelen ser de gran magnitud y de 'efectos' persistentes por lo que el problema merece atención inmediata y conjunta.

En muchos países capitalistas avanzados y algunos en proceso de desarrollo, las aguas o tierras de propiedad federal o nacional son arrendables o bien objeto de venta. Razón por la cual el uso de las mismas está sujeto al arbitrio del propietario.

En regímenes considerados de economía 'mixta' se hacen ensayos que establecen la propiedad social, como en Perú por ejemplo, o bien, en el caso de México donde se otorgan las especies principales en usufructo exclusivo (inclusive el cultivo) a los pescadores organizados en cooperativas. Este derecho no es enajenable o transferible.

En los países socialistas la propiedad de las aguas o tierras es del estado, quien la cede en usufructo a los trabajadores organizados colectivamente.

La tenencia y el uso del agua y la tierra implican aspectos políticos, sociales y económicos que están expresados en los instrumentos legales de cada país y forman parte esencial de su estructura jurídica.

El problema de mayor importancia al que se enfrentará la acuicultura, una vez definidas las formas de tenencia y uso del agua según las características políticas de cada país, será el de contar con agua en cantidad y calidad suficientes para el cultivo de las especies en cuestión. Esto sólo puede lograrse a través de medidas legislativas.

La cantidad es un factor crítico, por la gran demanda de agua requerida también por otras actividades económicas y uso doméstico, que suelen tener prioridad. Para lograr una distribución equitativa del agua debe ésta legislarse para el beneficio de los diversos usuarios y asegurar su calidad biológica. Si no se toman medidas oportunas la disponibilidad de agua, en cantidad y condiciones adecuadas, podrá ser el principal factor limitante de la acuicultura en años futuros.

Puesto que la acuicultura es la ciencia que se encarga de los cultivos de organismos en el agua, su desarrollo dependerá del uso racional de los recursos acuáticos, del régimen de tenencia, de la extensión y volumen, de los depósitos y de las necesidades urgentes que deban atenderse.

El uso de la tierra y el agua representan la causa principal de las conmociones sociales que sacuden sobre todo a los países del llamado Tercer Mundo.

Es necesario estudiar comparativamente cómo abordan y con qué objetivos sociales planifican la marcha de la acuicultura los países desarrollados y subdesarrollados del campo capitalista y socialista. Asimismo se deben conocer los mecanismos legales que formalizan y apoyan el cumplimiento de los objetivos sociales de la acuicultura en países que difieren no sólo por su desarrollo sino por su diferente estructura política, económica y social. En tanto que dicho análisis merece un estudio especializado y profundo, aquí sólo pueden subrayarse diferencias notables en objetivos sociales entre regímenes que todos los países encaran en los diversos aspectos tecnológicos de la acuicultura.

Ya se hizo notar que en muchos países subdesarrollados las urgentes necesidades alimentarias han determinado, aún cuando sea sobre bases empíricas (Asia y Africa, por

ejemplo), una evolución considerable de la acuicultura. Los países muy desarrollados del campo capitalista han impulsado la acuicultura para atender demandas muy específicas de la sociedad de consumo, incluso la producción de artículos de lujo, alimentos de alto valor comercial o bien para las necesidades recreativas como la pesca deportiva, en detrimento de la producción masiva para el consumo humano.

En todo el mundo se afrontan serios problemas de contaminación acuática. Debe tenerse presente que todo cultivo intensivo conlleva la propagación de plagas y enfermedades. En 1969 Noruega y Suecia prohibieron la importación de huevos de trucha procedentes de Dinamarca para evitar la introducción de enfermedades virales, en ese caso, la necrosis pancreática infecciosa. Las exportaciones danesas se han visto más tarde restringidas también por las disposiciones de otros países importadores de trucha, como los EE.UU. La FAO ha realizado eventos referente a las enfermedades de los peces, con el objeto de tomar decisiones comunes al respecto.

En muchos países la acuicultura ha contribuido a resolver agudos problemas sociales y económicos. No obstante, tiene aún poca significación general, excepto en el caso de algunos países asiáticos.

Las finalidades socioeconómicas de la acuicultura en el mundo contemporáneo debe dirigirse esencialmente a: (*i*) proporcionar trabajo y producir cantidades abundantes de alimento para atender las necesidades presentes y futuras de las masas humanas que habitan los países subdesarrollados; (*ii*) continuar proporcionando los bienes de uso y consumo que solicitan los países desarrollados (productos comestibles de exportación) y resolver los problemas técnicos que obstaculizan este comercio; (*iii*) ayudar a contrarrestar los efectos de la contaminación y evitar la destrucción irreversible de los recursos acuáticos.

Una estructura jurídica adecuada debe contribuir a la realización de los objetivos señalados.

3 Estructura jurídica nacional e internacional para normar el desarrollo de la acuicultura

Una de las recomendaciones más importantes de la Conferencia puede ser la convocación de una nueva reunión donde deberá surgir una Reglamentación Internacional que auspiciará la práctica y activará la extensión de la acuicultura. Dicha acción jurídica establecería condiciones para impedir el deterioro de las propiedades biológicas del agua, alteradas por efecto de la contaminación industrial, agrícola y urbana. Se puede seguir la pauta marcada por países desarrollados que han sentado las bases legales a través de acuerdos bilaterales o multilaterales, para encarar conjuntamente el peligro de un deterioro ambiental catastrófico.

Los Estados Unidos y Canadá firmaron en 1971 un acuerdo de grandes alcances dirigido a lograr la rehabilitación de los Grandes Lagos. Hay acuerdos internacionales también para impedir el avance de las plagas y enfermedades que afectan a los organismos acuáticos. Mediante la creación de agencias nacionales e internacionales y disposiciones jurídicas que funcionen igualmente en ambos sentidos se reforzará la lucha que la humanidad debe librar para asegurar su futuro.

Durante otra reunión se crearían instrumentos internacionales para la difusión de los objetivos y métodos de la acuicultura, sobre todo entre los países subdesarrollados.

En el ámbito nacional cada país debe decidir la forma de reglamentar el uso de la tierra y el agua, para cimentar las soluciones técnicas sobre un substrato adecuado de cambios sociales y económicos. La legislación interna debe ser congruente con los acuerdos internacionales sin menos cabo de los intereses nacionales.

Como ya se mencionó, uno de los obstáculos más serios para la realización de proyectos en acuicultura es la confrontación frecuente con la política regional en la utilización de tierras y agua, puesto que compiten con la alta demanda de agua de la industria, la agricultura, la ganadería y el consumo doméstico. Ante esa situación debe demostrarse la conveniencia y factibilidad del uso múltiple del agua y proceder a establecerlo jurídicamente. En México, por ejemplo, la Ley de Aguas reglamenta su uso y concede prioridad a las necesidades domésticas, incluye también su aplicación con fines acuícolas y crea los Distritos de Acuicultura con el objeto de asignar en cada caso los volúmenes necesarios a ese propósito.

Otro aspecto que debe ser legislado tanto nacional como internacionalmente es el referente al peligro de la introducción y dispersión de plagas y enfermedades, que frecuentemente abaten la producción o impiden el comercio de los productos derivados de la acuicultura. En tales casos procede la aplicación de una Legislación Cuarentenaria semejante a la utilizada para la producción agrícola y ganadera. Se han tomado ya algunas resoluciones internacionales al respecto.

4 Conclusiones y recomendaciones

El desarrollo de la acuicultura en el mundo es tan desigual como el desarrollo económico, pero no coincide necesariamente con éste. Hay países subdesarrollados económicamente que muestran sin embargo un excelente desarrollo en la acuicultura.

La acuicultura ha desempeñado y desempeña un importante papel en la solución de problemas socioeconómicos que afectan a los países subdesarrollados (empleo y alimentación).

Es necesaria la integración horizontal y vertical de la acuicultura, dotándola a escala nacional e internacional de estructuras jurídicas a través de las cuales se ordene y fomente su desarrollo.

Bajo las diferentes condiciones de infraestructura socioeconómica y legal se observan las formas más variadas de afrontar los problemas y la planificación de la acuicultura, aunque siempre en torno a los lineamientos generales derivados de la experiencia de los países acuicultores tradicionales y de aquéllos que han desarrollado tecnologías elaboradas. Los métodos se aplican ajustándolos a las condiciones naturales y a los problemas socioeconómicos de cada país.

Del conjunto de circunstancias concretas surgen las diversas estrategias de desarrollo que se observan en el mundo y se plasman en cuerpos de ley que norman la acuicultura y la encauzan hacia el cumplimiento de sus fines.

Las disposiciones legales que se aplican actualmente se refieren a aspectos esenciales para la práctica de cualquier actividad económica, a saber: (*i*) disposiciones legales que rigen la tenencia y uso de tierras y aguas; (*ii*) legislación que establece las condiciones bajo las cuales debe practicarse la acuicultura, inclusive las normas limitativas para la importación indiscriminada de especies exóticas y para evitar la

introducción y propagación de plagas y enfermedades; (*iii*) legislación para evitar, controlar o aminorar la contaminación de las aguas y asegurar condiciones propicias para la acuicultura.

Una legislación internacional deberá tener finalidades semejantes, que conduzcan a conservar e incrementar la productividad acuática y a lograr que la acuicultura aporte medios de vida que amengüen la escasez mundial de alimentos protéicos.

La administración científica de los recursos acuáticos conducirá al uso múltiple de los mismos y entre las aplicaciones más sobresalientes merece especial atención la acuicultura, como una de las mejores expectativas para encarar con realismo la incertidumbre del futuro.

Las Naciones Unidas deben unir su esfuerzo para dar a los pueblos del mundo un instrumento jurídico que propicie la conservación e incremento de los recursos acuáticos a través de la aplicación y completa integración de la acuicultura.

Problems of Large-Scale Vertically-Integrated Aquaculture

H. H. Webber and P. F. Riordan

Abstract

As aquaculture evolves from small scale fish farming (sometimes only family size or on a subsistence basis) to the level of large-scale agribusiness enterprises, its problems proliferate.

It is expected that world aquacultural production will exceed the present value of the capture fishery before the end of the century. This increase will occur primarily through growth of large-scale vertically integrated aquacultural enterprises (*ie*., centrally managed systems in which all components of the system from original provision of energy to final marketing of the product are co-ordinated).

The problems of vertically integrated aquaculture are outlined, they are concerned with: species limitations (in the market, biological and technological), site selection, feed, manpower needs, and legal, institutional and financial requirements.

The gaps in understanding of, and the constraints limiting, large scale aquaculture are listed, and courses for future action recommended with respect to: types and diversity of species to be cultivated, marketing, biotechnology (seed supply, disease control, water quality and concerted effort), siting, feed, manpower, legal and institutional aids (provision of water rights, grants, tax breaks, duty-free imports, *etc*.), and adequate financing.

The lack of hard data based on experience suggests that large scale vertically integrated aquaculture is a high risk enterprise, and with the high capital investment required, banks and funding institutions are wary of supporting it. Investment in pilot projects is suggested to demonstrate that large-scale aquaculture can be a fully functional and successful business. Construction and operation of such pilot farms is judged to be in the interests of both the public and private sectors.

Les problèmes de l'aquaculture de grande échelle à intégration verticale

Résumé

A mesure que l'aquaculture evolue, passant des exploitations piscicoles de petite echelle (parfois seulement d'importance familiale ou travaillant sur une base de subsistance) pour se hisser au niveau d'agro-industries de grande echelle, ses problèmes se multiplient.

L'on escompte que la production de l'aquaculture mondiale excédera la valeur presente des captures de la pêche avant la fin du siècle. Cet accroissement sera réalisé en premier lieu grâce a la croissance des grandes entreprises aquicoles à intégration verticale, qui sont des systèmes à gestion centrale dans lesquels toutes les composantes sont coordonnees, depuis l'approvisionnement initial en énergie jusqu'a la commercialisation finale du produit.

Le document esquisse les problèmes de l'aquaculture à intégration verticale: les contraintes d'ordre spécifique (sur le marche, des points de vue biologique et technologique), le choix des sites, l'alimentation, les besoins de main d'oeuvre, les exigences juridiques, institutionnelles et financières.

Le manque de connaissances sur l'aquaculture de grande échelle comme les constraintes qui en constituent les facteurs limitatifs sont énumérées et l'on recommande des modalités d'action pour l'avenir dans les domaines suivants: types et diversité des espèces d'élevage, commercialisation, biotechnologie (approvisionnement en geniteurs, lutte contre les maladies, qualité d'eau et efforts concertés), choix des sites, alimentation, main-d'oeuvre, aide juridique et institutionnelle (octroi de permis, subventions, exonérations fiscales, importations en détaxe, etc.) et financement adéquat.

Le manque de données précises fondées sur l'expérience permet de penser que l'aquaculture de grande échelle à intégration verticale est une entreprise qui s'expose à gros risques. Etant donné les gros investissements qu'elle nécessite, les banques et les institutions de crédit hésitent à la financer. L'on propose de procéder à des investissements dans des projets pilotes afin de démontrer que cette activité peut être une entreprise pleinement fonctionnelle et fructueuse. L'on estime que la construction et le fonctionnement de telles exploitations pilotes serviraient les intérêts tant du secteur public que du secteur privé.

Problemas de la acuicultura a gran escala integrada verticalmente

Extracto

A medida que la acuicultura pasa de actividad a pequeña escala (a veces meramente familiar o de subsistencia) a empresa comercial a gran escala los problemas proliferan.

Se espera que antes de finales de este siglo la producción acuícola mundial sea superior al valor actual de las capturas pesqueras. Este aumento se debera ante todo al desarrollo de las empresas de acuicultura a gran escala integradas verticalmente, es decir, sistemas administrados centralmente en los que todas las fases, desde la aportacion original de energia hasta la comercializacion final del producto, están coordinadas.

Se señalan los problemas de la acuicultura integrada verticalmente, limitaciones de especies (por razones de mercado, biológicas y tecnológicas); seleccion de emplazamiento, piensos, necesidades de mano de obra, y requisitos juridicos, institucionales y financieros.

Se enumeran las lagunas aún existentes en los conocimientos sobre la acuicultura a gran escala y los obstáculos que se oponen a su desarrollo y se recomiendan algunas lineas de accion para el futuro en lo relativo a: tipos y diversidad de especies que han de cultivarse, mercadeo, biotecnologia (suministro de semillas, control de enfermedades, calidad de las aguas y esfuerzo concertado), emplazamiento, piensos, mano de obra, ayudas juridicas e institucionales (concesión de derecho de uso de las aguas, subvenciones, exenciones fiscales, importaciones libres de derechos, etc.) y financiacion adecuada.

La falta de datos sólidos basados en la experiencia hace que la acuicultura integrada a gran escala sea una empresa muy arriesgada y, dadas las grandes inversiones de capital que son necesarias, los bancos y las instituciones financieras se muestran muy cautos a la hora de apoyar esas actividades. Se sugiere que se hagan inversiones en proyectos piloto para demostrar que la acuicultura a gran escala puede ser una empresa perfectamente funcional y fructífera. Se estima que la construccion y funcionamiento de explotaciones piloto de ese tipo responde a los intereses del público y a los del sector privado.

1 Introduction

As aquaculture evolves from the small-scale fish farms owned and operated by the single family unit primarily for subsistence or at best for a small cash crop - into large-scale agribusiness enterprises incorporated and conducted for economic profit, many new problem areas are engendered and many of the old problems become more critically significant.

When subsistence or the family food budget is the underlying motivation for undertaking farming, the criteria for success or failure are those that relate essentially to the survival of the family, and economic profit or loss is rarely measured or judged. However, a corporate entity designed to generate a profit cannot compete in the market place with subsistence farmers who are merely making a living unless it can provide a favourable return on equity to its shareholders. Consequently, what may in fact be a tolerable condition for subsistence aquafarming as a way of life, may be a problem area of major consequence to corporate, vertically-integrated large-scale aquaculture (VIA) as a wealth generating enterprise.

It is, therefore, not scale alone which differentiates between these two forms of endeavour, but rather the purpose, motivation and the *modus operandi* which define the differences. The consequent applicability within the framework of the socio-economical political status and development goals of the society must be judged accordingly.

1.1 *Aquacultural production*

There is a rapidly advancing technology evolving in Asia, Africa, Europe, and in the Western Hemisphere that promises to make the aquaculture industry a correlative of modern terrestrial agribusiness. This new aquaculture is maturing without necessarily recapitulating all the slow empirical growth phases of traditional agriculture, and can now be viewed as being the incipient stage of a comprehensive industrial production-processing-marketing system. Nevertheless, VIA as an aquatic animal husbandry industry, when viewed as an analogue to terrestrial animal husbandry, is in an early stage of development. It is still on the lower part of the learning curve.

1.1.1 *Current production.* At present, aquaculture provides only a small supplement to human food supply. In 1973, about 5 million tons of fish and shellfish were produced by culture, whereas 65 million tons were produced in the total capture and culture fisheries of the world (FAO, 1973). However, since this latter figure includes a sizeable amount of industrial fish, a more useful comparison can be made with fish caught for direct consumption. When thus compared, aquaculture is found to yield 11 per cent of the total aquafoods consumed by man. As the catch fisheries level off at optimum sustainable yields, and the needs and demands of an increasing population apply mounting pressure on the world food supply, the significance of farmed aquafoods will become even more evident to national planners and private sector investors.

1.1.2 *Projected production.* It has been predicted (TAC, 1973) that by the year 2000, aquaculture could produce at least 50 million tons of animal protein if certain research and development measures were undertaken. There are in the order of 440 million ha of coastal wetlands in the world, mostly mangrove swamps in the tropics. If only 10% of these were utilized in coastal aquaculture, even employing the lower productivity techniques of the traditional subsistence farmer, 100 million tons of aquafoods would be produced (Ryther, 1975). FAO estimates that the potential annual sustainable yield from the world's commercial capture fishery may not exceed 100 million tons of fish and shellfish, of which a considerable portion will be industrial fish not directly consumed by humans. A comparison of potential yields thus suggests that aquaculture could become an even more significant source of human foods than the total capture fishery. Furthermore, if the high productivity methods of large-scale sophisticated industrial aquafarming were employed, then three to five times this projected volume could be produced. With improvement in productivity and the greater systems efficiency that will result from continuing research and development in both biological and engineering technology, we predict that aquacultural production will exceed the present value produced by capture fisheries before the end of the century.

1.2 *Definition of large-scale vertically-integrated aquaculture (VIA)*

By VIA enterprises, we mean those comprehensive systems which are centrally managed so that all the components of the system, from the input of energy from the sun to the final sale of the product in the marketplace, are co-ordinated and kept in balance.

2 Problems of large-scale vertically-integrated aquaculture

Although the long-term future growth of the world aqua food supply will probably come from VIA, this fledgling industry has many problems to face and overcome before this becomes reality.

2.1 *Species limitations*

VIA enterprises gain their primary justification from the demands in the marketplace. In fact, it is most appropriate to consider vertical integration as proceeding backward from the market through to processing and production, much as many trading companies have matured to have command over the generation of the products that they can readily sell in the marketplace.

2.1.1 *Market.* Major problems of VIA that have their origins in the market include: (*a*) small scale; (*b*) static demand; (*c*) limited acceptability; (*d*) high price-elasticity; (*e*) preservation problems; (*f*) processing problems; (*g*) distribution problems; (*h*) competition from other aqua foods; (*i*) competition from other protein goods.

For example, the oyster industry in the United States is capable of producing more half shell oysters than the market will absorb at an attractive price. Worldwide, oyster acceptance is localized and there are many populations which reject these molluscs. Among the deterrents to the expansion of the oyster market there is a lack of shucking skills or satisfactory automatic devices to accomplish shucking at the processing and consumer levels.

The trout market in the United States and Europe has remained relatively steady over the past two decades and prices have not kept pace with inflation or the prices of animal protein foods including other fish (Erkins, 1975).

Some species which have gained attention from investors appear attractive because they command a high price in the market, and can be grown to market size on an experimental basis. Pompano (*Carolinus trachinotus*) is an example. It was the most valuable finfish in the United States on a per pound basis. However, this is true only because the supply is very limited and, therefore, a VIA based on this fish could not succeed if the plan depended on maintaining the present price structure. In fact, this price-elasticity was a contributing factor to the failure of several ventures to raise pompano in Florida.

The homarid lobster is another very price elastic aquafood. The market is attractive and currently of high value. However, any aquaculture venture must take into account a reasonable selling price reduction for an operation producing tens of millions of pounds.

2.1.2 *Biological.* The biological problems of VIA are in large measure a function of large scale, high density and high technology; or at least they become major problems by virtue of size. Some biological problems which plague

VIA are: (*a*) disease and parasites; (*b*) seed production; (*c*) predation and competition; (*d*) inventory control; (*e*) nutrition.

In finfish culture, losses due to diseases and parasites occur too frequently, and can only be controlled and eventually prevented after gaining considerably more practical experience with high-density culture which teaches us how to limit the course and extent of diseases. The Danish trout industry is an example of an aquacultural industry that has been severely limited by disease. A virus which infects the channel catfish (*Ictalurus punctatus*) in the early fingerling stages has caused appreciable mortalities in the southern United States.

As more crustaceans, such as shrimps, lobsters and crabs, are grown in confinement in high population densities, one may expect to encounter disease and parasite problems which have not as yet imposed any serious constraints on aquaculture production of these forms. Reports of diseases of shrimps and lobsters due to fungi similar to *Dermocystidium* and bacteria of the genus *Vibrio* have been published, but are still infrequent occurrences, whereas diseases due to certain parasites, such as microsporideans, gregarines, and cestodes are reported more frequently. Certain worms, such as trematodes and nematodes have been noted as parasitic on penaeid shrimps, lobsters and other decapods.

Molluscan mariculture has frequently been seriously constrained by diseases, and in several instances disease has been reported to be the primary factor in curtailing or eliminating oyster culture in large littoral regions in the Northern Hemisphere. Malpaque Bay disease in the Canadian Maritimes, MSX disease in Chesapeake Bay and the recent devastation of the Portuguese oyster (*Crassostrea angulata*) in Portugal and France are typical of disease outbreaks in established oyster cultures.

A serious problem common to extensive culture in intertidal confinements or embayments is the cost and difficulties encountered in the production of seed animals. For instance, it appears that the supply of eyed eggs is now the limiting factor on the growth of salmonid culture in the United States (Klopfenstein and Klopfenstein, 1975). Most often in the lower latitudes there has been a dependence on natural recruitment of juveniles on a tidal influx or from trapping or netting in the surf, as, for example, with the milkfish (*Chanos chanos*). Although considerable effort has already been expended in laboratory and even pilot culture programmes to understand the reproductive physiology of penaeid shrimps, success on a commercial scale has not yet been achieved. Until completion of their life cycle in captivity is realized, there will always remain the serious risk that we shall be unable to procure at the appropriate times a sufficient number of healthy gravid females from the wild penaeid populations to bring into our hatchery to sustain an economic scale of production. The risk is similar when we are dependent on the capture of finfish fry or natural molluscan spat-fall.

In a water management system, where surface water is used to maintain the health of the grow-out facilities, there is the problem of the introduction of aquatic predators and competitors into the ponds. Eggs or larvae of undesirable aquatic 'weed' animals may be introduced into the culture waters as airborne inocula or on the legs of wading birds. Although useful in the case of starfish infestation of oyster beds, chemical means have not successfully controlled mollusc predators, such as the oyster drill, or crabs which prey on clams. Water fowl and certain terrestrial animals are also predators as, of course, are certain predaceous finfish. Birds can decimate a crop of shrimps or fish and are a problem in many operations.

A serious limitation in our ability to manage dense populations of aquatic animals in intensive culture is a consequence of an inability to determine quantitatively the absolute numbers of animals in the confinement. Without precise measurements of the number of animals in the production system at any one time, many of our efforts to manage water quality, feeding rate, disease, *etc*, are frustrated.

Lack of knowledge regarding nutrition of several candidate species interacting with other significant variables exercises a powerful leverage on the health of the animals as well as the economic health of the venture.

2.1.3 *Technological.* Although the technology of the various parts of many aquacultural systems is developed so that technology *per se* is seldom limiting, the components are not always completely integrated into a working system.

One major technological problem relates to pollution, a deterrent to culture both in the context of pollution by external sources and because of a need to reduce the polluting effect of the culture effluent. Pollution of the coastal zone which is widespread throughout the world has a very deleterious effect on VIA. Furthermore, pollution enhances fouling of net fencing and screens, and is a serious problem in embayment aquaculture (Huguenin and Ansuini, 1975).

High density culture of aquatic animals in confinements, which requires the use of large quantities of organic matter in the form of formulated feeds, results in a commensurately large amount of faeces and other waste products. The expulsion of these waste products into the environment may be a source of considerable pollution if not properly managed. As a point source of eutrophication, aquafarm effluents can be as serious an insult to the environment as urban domestic wastes. Consequently, pollution abatement practices and costs must be factored into the plan and operating budget of VIAs. In a modelling study of intensive homarid lobster culture, by the Bodega Bay Laboratory of the University of California, the cost of pollution abatement was noted as limiting of the enterprise's commercial validity.

Other technological problems relate to control in intensive closed culture systems. Although there are many such systems in the experimental or pilot phase, no full-scale aquaculture venture operates profitably using this technology.

2.2 *Sites*

Poor siting of large aquafarms has been a major contributing factor to poor performance of many ventures resulting in some cases in total failure of the business (Webber, 1972).

In the selection of an appropriate environment in which to operate an aquafarm, it is obvious that a primary limiting factor is water quality, including temperature, salinity, dissolved solutes, bacteriological and viral content, turbidity, colour, detritus content, pH, hardness, and alkalinity. This is a major problem if not confronted before the decision to start a venture.

The location of Marifarms in Panama City, Florida, where winter temperatures are inappropriate for year round growth, has been a significant problem in achieving economic success. Crops have been lost due to winter freezes. However, because of a major commitment in capital construction and improvement, the company has been unwilling or unable to move closer to the tropics.

Depending on the production methods to be used, many other criteria must be satisfied in order to optimize profit by reducing capital requirements and operating costs, and by increasing productivity. Among factors critical to a decision are: (*i*) prevailing meteorological conditions, *eg*, wind, light, air temperature, relative humidity, evaporation rate and precipitation; (*ii*) edaphic factors, *eg*, soil type, percolation rate, topography, soil chemistry and mechanics; (*iii*) hydrological characteristics, *eg*, tidal or river flow rates and volumes and ground water or aquifer supply and movement. Particularly if pond or earthen raceway culture systems are planned, topography and run off characteristics can materially influence construction costs.

The availability of earth-moving machinery and other construction equipment and skills, as well as ready access to the diversity of materials and supplies for the construction and operation of laboratories, hatcheries, processing and other such facilities must also be factored into the site selection decision.

The high dependence of aquaculture on labour inputs imposes a critical need to locate the facility where these resources are resident and readily available. The alternative, such as constructing a camp with labour housing and support services, may prove to be an economic burden to impose on a start up aquafarm.

Because aquafarms are frequently sited in low wetlands, along river courses, or in coastal marshes, they are particularly subject to the damaging effect of storms and floods. To locate a capital intensive aquafarming venture in the common path of hurricanes, tornados, typhoons or other violent storms is to invite risks that are not worth the return. An example of this is Pragua, S.A., of San Pedro, Sula, Honduras, which, after confronting and solving many production problems in catfish farming, was completely destroyed by a hurricane and its consequent flooding. A similar hurricane had passed over essentially the same course just three years previously.

The socio economic climate in which the aquafarming business is to be conducted can be a major determinant in the success of the venture. The attitude of government regarding industrial versus agribusiness development can also be a significant influence on the success of an aquaculture venture. National policy regarding incentive programmes, such as the abatement of import duties on essential equipment and supplies, income tax abatement or deferment, the legal structure regulating the use of coastal zone or wetlands, land use and water resource patterns of development, and the availability of concessions for public lands and water, are all important contributors to the technical and economic management decision regarding the choice of a site.

When one or more of the essential site requirements cannot be satisfied, such as when year-round water temperature or supply seriously curtails production, or does not allow for growth rates that are competitive with production at other locations, or when an intrusion into the culture system of industrial wastes or agricultural biocides induces high mortalities, or when the project is burdened with import duties on essential machinery or supplies, or when labour is costly and intransigent, then obviously the business will be seriously impaired. VIAs may be more vulnerable to these site sensitive effects than small rural farms.

2.3 *Feed*

Feeding with specially formulated rations to provide a complete diet in the case of closed systems, cages or baskets, and raceways, or a diet supplementing natural productivity in the case of static pond systems constitutes a major expense and provokes a complex of problems. VIA must eventually include feed production in its system. At the present time, except for some established feed manufacturers who are in many cases new to aquaculture, most companies are purchasing a formulated ration.

Since the feed formulations so far developed for most aquatic farm animals rely upon several essential and costly components for their nutritional effectiveness, and since the feed cost represents such a high proportion of the operating expenses, the economics of the aquaculture industry are particularly sensitive to variability in cost of the commodities which enter into the feed formulation. For instance, Peruvian fish meal, made from anchoveta harvested off the Peruvian Chilean coast, increased inordinately in price in 1972–73 as a consequence of the reduced catch of these industrial fish. This was reflected in increases in the cost of formulated animal rations, which in turn affected the economics of aquaculture projects.

Feed considerations also have a strong impact on siting decisions since the absence of indigenous feed components can negate the economic viability of a venture located in areas remote from commercial feed sources.

2.4 *Manpower*

Lack of appropriate manpower at all levels of the company from top management to farm labour is and will continue to be a critical problem.

Although most VIA is capital rather than labour intensive, it will still employ large numbers of wage and salary earners. Lack of a trained or experienced personnel pool at the middle and lower skill levels is a serious problem in a start up situation.

Because of the current interest in aquaculture, there appears to be an adequate and growing number of people college-educated in science, and trained in technology, available for the biological and engineering phases of aquaculture. However, very few of these have any hardened, on the-job, 'hands on' experience. Skilled and experienced workers remain a limiting consideration in staffing an aquafarming business.

The lack of highly qualified agribusiness management may still constitute a major problem in maintaining aquaculture ventures.

An aquatic animal husbandry business requires a very special manager. In common with managers of other agribusinesses, beyond sound business sense and knowledge, he must possess an active and working awareness of the vagaries of biological processes. This awareness must operate in concert with a set of attitudes that allows for considerable variability in productivity as a consequence of capricious weather, or other out of-control forces. He must have the intellectual agility and the emotive capacity to confront

unpredicted and unwanted change and to be promptly responsive with the appropriate remedial action.

The management structure for large scale aquaculture operations generally follows the patterns of other corporate or co-operative business organizations. The skills required for directing the various diverse essential functions of a vertically-integrated agribusiness can rarely be provided by one or a few individuals. Thus, a team of specialists is often required to be assembled that represents: the disciplines of corporate planning; finance and investment promotion; various technologies, including engineering design and construction; both broad and specialized biological sciences; and food science including processing technology. Finally, marketing and merchandising skills must be enlisted to monitor the demand and to design and carry the product in appropriate forms into the market place. The organization of these disciplines into a working system requires the very special competence of a general manager or chief executive officer which has so often been lacking in recent attempts to organize vertically-integrated aquaculture. Probably the most critical single requirement of the manager, in common with the need in most business organizations, is the ability to deal with people in a way to engage their full co operation in the operations and to engender a commitment to the success of the venture. In common with any large complex interdisciplinary production system, depending on the diversity of skills that only people not machines can provide, the VIA enterprise requires a strong leader who can direct and stimulate the people around him to success.

It is probably true that the individualistic personality with the requisite technical skills and the attitudes of entrepreneurship which can motivate him to live and work with the uncertainties of a start-up aquaculture venture, often in remote areas, has a strong instinct against the strictures of the organization. Although committed, and willing to work hard, he may not be willing to subordinate his personal goals to those of the organized effort.

2.5 *Legal and Institutional*

Many problems in large-scale aquaculture have arisen not from biological, engineering or other technical aspects of the production system, but as a consequence of the socio-economic ambience in which the enterprise is conducted. There are many legal and institutional constraints on the operation of a business that is designed to use waters generally judged or taken to be in the public domain. Such waters include the littoral region at the edge of the seas, great ponds and public reservoirs, lakes and rivers, and even private reservoirs that become integral parts of the overall water resources management system of a region. Even if concessions or leases can be procured from public regulatory agencies, the extensive water and land developments of large scale aquaculture become attractive poaching grounds for people who judge that aquatic animals are part of the commonwealth, and are thus subject to open fishing. Surveillance and security become more of a problem in large-scale aquaculture than in subsistence or family farms where the areas are small and the owner lives nearby.

Such custom, sometimes crystallized into law, has made the capture of aquatic animals for human food a public prerogative to all members of the community. These practices, which have been so long a part of the culture, are difficult to change and have, for instance, served to limit the growth of large-scale molluscan aquaculture in many parts of the world.

The 'maritime mile' that is often defined as a strip of coastal land some distance inshore from the mean high tide mark was originally set aside by many governments as a security area for military purposes and for the control of the movement of contraband. With the increased awareness of the ecological significance of the coastal zone, and of the estuarine habitats as nursery grounds for many commercial and sports fishery species, governmental controls over these regions have become more strict and exploitation for private use has become more difficult.

Some large scale aquafarming undertakings have encountered great difficulty in procuring both governmental and popular approval for use of public waters for pen or embayment cultures. The arguments presented against these proposed farming ventures include the following: interference with navigation by floating pen structures, unsightly obstruction of the view and other arguments based on aesthetics; interference with commercial or sport fishing; and finally the argument that the effluent of the aquafarm is a serious organic pollutant.

2.6 *Financial*

As a consequence partly of the difficulties noted above, many aquaculture ventures have been unsuccessful in enlisting the necessary early investment capital. Adequate enlightened financial support is necessary to pursue the development over a sufficiently long term to enable the enterprise to gain the experience necessary for sound projections and corporate plans.

The undercapitalized condition has frustrated a great many ventures which might well have become important and profitable food producers, if they had been able to sustain the momentum of the initial commitment throughout the development period.

We have observed that undercapitalization reflects not only reluctance on the part of venture capitalists to commit sizeable equity funding to new aquaculture ventures, but it is equally true, and even more frustrating to find international, national and local development bankers, and the venture analysts employed by them, behaving so conservatively and demanding such high degrees of assurance and guarantee, that a reasonable loan capital component is very difficult to negotiate. Often undercapitalization is a consequence of the venture being oversold by the scientist whose enthusiasm and optimism may blind him to the realities and the time frame of commercial development. A realistic perspective on this scene is most readily achieved from a 'hands on' experience and since commercial aquaculture is so new an endeavour, often the technologists are too inexperienced, and there is too little empirical evidence available from which to project realistic costs and time for the development of VIAs.

3 Gaps and constraints and recommended courses for future action

Having earlier characterized the major problems confronting VIA, we may now identify the major gaps in our understanding and the constraints which limit aquaculture, so that, in effect, we may also suggest a course of future action.

Large scale aquaculture must be viewed as a high risk

undertaking whether performed by private industry or in the public sector. These risks have their origin not only in the maze of uncertainties that new industries confront as old arts are translated into new technologies, but also because many forms of large-scale aquaculture must still be viewed as being in the start-up phase and new bio-engineering is still being developed. Invention of new techniques and adaptation of those which were developed elsewhere are sources of risk which will continue to frustrate the development of aquaculture. Although an adequate methodology exists in all phases of culture, processing and marketing of several species, there still remains the need for more pragmatic systems development (Webber, 1973).

3.1 *Species related*

As VIA industry grows, there may be a justification for considering the use of highly developed techniques in the culture of a greater diversity of species. However, the decision to grow a particular species of plant or animal in a commercial aquacultural system requires a detailed evaluation of a great and disparate number of considerations. Many of the obvious gaps and constraints which, if resolved, promise early success are species related.

On the other hand, when one views the experience with terrestrial animal husbandry, we find only a few species intensively investigated and developed. It is also true that the successfully domesticated terrestrial species are herbivores, or, as in the case of swine and poultry, omnivores which readily adapt to a diet based predominantly on vegetable protein. Generally, no carnivores are cultured, probably because of poor cost effectiveness in the management of food energy.

3.1.1 *Market.* VIA enterprise will be dependent on a worldwide system of market monitoring to identify: species and product form (*eg*, live, fresh, frozen; round or gutted or filleted; or processed into a convenience food); packaging; price levels; control of portion size; transportation requirements; quality requirements in terms of wholesomeness as well as in terms of taste, colour, texture and other such values. For institutional markets, appropriate gross shipping weights, delivery schedules and numerous handling requirements must also be satisfied.

Ultimately, the most significant market criteria of concern to the VIA industry are the size and structure of the market and the elasticities of price and demand for the products which can be produced from the species which are grown. This information must be available on a worldwide basis because of the inter relation of various national markets. For example, the penaeid shrimp price in the United States is influenced by what the Japanese will pay, and *vice versa*. Such worldwide market intelligence is not now available and constitutes an obvious gap in knowledge which makes planning a large-scale venture more precarious. Differences in acceptance criteria among markets can also contribute to failure or profitability.

Since aquaculture is viewed by many as an ancillary arm of the fishing industry, which operates with the attitude of a raw material producer seeking a purchaser, the assumption is often made that vertical integration of aquaculture should progress from production toward the market-place. However, with the capacity of aquacultural systems to command production rather than depend on a hunted resource, it is possible to insert products into the market specifically in response to demand. A restructuring of the fish marketing system for a production oriented marketing to a market-oriented production, provides vertically integrated aquaculture with the most appropriate business strategy (Coale *et al*, 1974).

3.1.2 *Biotechnology.* A cluster of enigmatic variables influencing the interaction of the many biological parts of an aquatic animal husbandry system appears as a serious gap in our knowledge. Some of the biological parameters can only be understood by acquiring fundamental knowledge of the physiology and behaviour of our crop animals.

An assured seed supply must be achieved. This should be accomplished through the operation of a managed breeding programme with animals whose gametogenesis is controlled; where mating, larviculture and nursery culture can yield an abundance of healthy young of known genetic composition. This capability is essential and is not now certain for all species which are being cultured. It is precisely because of this concern that we seek to operate in regions in close proximity to reliable, high productivity spawning and/or nursery grounds where young may be recruited from natural stocks. Although this wild source of young will suffice for the present, long-term success of aquaculture and stock improvement requires a closed life cycle under the command of the culturist.

Lack of knowledge of disease can also limit success. We must identify the etiological agents and determine efficacious therapeutic procedures in order to limit disease outbreaks. Most importantly, we will have to develop prophylactic practices to avoid the conditions which induce diseases. We can be encouraged from our experience with terrestrial animal husbandry systems, where we have learned how to use antibiotics and other pharmaceuticals to treat certain diseases.

It is of even more consequence that we manage the grow-out facility and learn how to avoid the imposition of environmental stress, which apparently predisposes the animals to attack by ubiquitous disease inducing organisms. The inadvertent introduction of alien species bearing disease organisms or parasites must be avoided. However, appropriate quarantine measures, properly administered, should enable the domestication of new animals for husbandry without incurring inordinate disease incidence. These measures should be instituted voluntarily by VIA enterprises.

High population densities in cultural confinements demand sophisticated monitoring of water quality and crop animal hygiene. There is also a need for better ecological management to prevent or lessen the severity of oxygen depletion, disease and parasite attacks, predation and competitition.

There appears to be sufficient technical knowledge about several species, drawn from the early experience of the culture of aquatic animals as an art, and from the very considerable body of fundamental biological knowledge. Even at this early stage of the evolution of aquaculture as an industry, technology, *per se*, is not the limiting factor in the development of profitable VIA enterprises for several species already qualified.

However, even though the technology is available for all the components from seed production to marketing, what is still lacking is the operating system in which the components function in concert. Although the technology may not

be limiting, this incipient industry has a dearth of on-the-job experience and a lack of cost accounting history for each of the many steps in the process. As noted above, the industry is thus fraught with much uncertainty regarding profitability.

3.2 *Sites*

Whereas the scientific basis for culture and management of high density, high productivity aquaculture has had its theoretical development in temperate zone laboratories and experiment stations, the more appropriate geographical areas for practical application of the technology of certain species are proving to be in selected regions of the warm-water environments of the tropics and sub-tropics. Year-round warm water and high productivity allows for year-round harvests which in turn lends a competitive advantage over capture fisheries since a continuity of supply can be assured to market. Since the biological systems to be managed are extremely sensitive to the many influences of the environment, technology transfer has been slow as the process of adaptation of basically sound knowledge to new aquacultural ecosystems has been progressing. The most economic means to achieve this transfer and to gain the experience and generate the engineering data for scale-up to commercial size is in a pilot farm.

In some lesser developed countries, lack of infrastructure can be limiting to the success of a poorly thought-out venture. On the other hand, expansion of infrastructure into the rural sector is often an additional consequence of large-scale aquacultural development. A development plan for aquaculture for the lesser developed countries of the world should, therefore, include as one of the options large scale vertically-integrated systems with the considerable attendant investment funds for justifiable infrastructure development. These may better satisfy some of the goals of a developing country than would a complete dependence on small-scale subsistence aquafarming.

3.3 *Feed*

The feed bill may be the largest single item in the operating budget of an aquafarm that grows species depending on formulated rations for a significant portion of their diet. Feed formulation for aquafarming use has been generally based on experience with salmonids. Cost efficient, nutritionally sound formulations remain to be worked out species by species. Optimization of feed from both the nutritional and cost aspects is a promising area of new work. For example, the feed cost is one of the limiting factors to the viability of large scale homarid culture which must be conducted without benefit of natural productivity in the culture water.

To relieve some of the dependence on a formulated, pelleted and complete ration, the aquafarming venture may be deliberately designed and situated so as to enable a significant portion of the nutritional requirements of the cultured organism to be provided out of the natural productivity (Webber, 1975). A high natural production in the form of improved pasturage would be required in a grow out environment to increase its carrying capacity in order to sustain a large crop biomass in a limited volume of water. To achieve this goal, a great deal of additional scientific investigation must be undertaken to insert soluble nutrients propitiously and to explicate sound management of the aquacultural ecosystem.

Clearly, an aquafarming venture may be designed to take advantage of the increased return per increment of investment that polyculture can provide at the same time that pollution abatement is achieved. Hence, the species to be grown must be critically chosen to integrate into the various ecological niches that will be provided by controlled environments in the culture system (Sarig and Marek, 1974). The opportunity to recycle wastes through several coprophagous animal species and certain plant species, such as the macro-algae which can remove the soluble nutrients from the effluent of a polyculture community can be of considerable economic advantage, worthy of deliberate species and site selection (Ryther and Goldman, 1975). Such strategies reduce the polluting effect of the aquafarm itself, and also conserve and utilize the total energy of the system more efficiently.

3.4 *Manpower*

The highly productive food and fibre agribusiness enterprises of the world have matured into vertically diversified industrial systems and can serve well as analogues for the developing aquatic food industries (Goldberg, 1975). Successful management personnel may well be recruited from land based agribusiness enterprises because of their experience and attitude toward biologically based industry.

What is lacking and required is manpower development at middle and lower levels of farm management. Technicians and field workers will be required in the hatchery, the nursery, the grow-out facility and for harvesting. The majority of these may best be trained in the field, in the country, and in the language of the country where the farm is to be located. Other workers could be trained in regional centres. Although extension services are more important to small-scale rural aquafarming than to large-scale VIAs, they are needed in both systems. Pillay (1977) has discussed these needs in more detail and offered appropriate solutions.

3.5 *Legal and institutional*

A major gap in the plan for successful large-scale VIA is the lack of laws which define aquaculture as one of the valid competing uses of public waters.

Private property is more difficult to define and defend when it is under water, as noted above. In most societies around the world, and particularly in the developing countries, waters supporting food fish are judged to be in the commonwealth and in the public domain; it is felt, therefore, that they should be accessible for fishing by all members of the society. This principle is deeply embedded in many cultures around the world and may constitute a serious risk to aquaculture. VIAs may require expensive surveillance measures to protect the investment of the private owners. The legal and cultural context in which the release and recapture type of aquaculture called ocean ranching can be practised is not yet clarified for most river systems and coasts, and consequently, the practices are still fraught with controversy in some regions.

Pen culture of finfish, for example, salmonids, often uses public waters, such as bays or fjords, coastal lagoons, sounds or other sheltered aquatic environments. Public permission to intrude on these domains must be procured, not only through legal and regulatory channels, but there must also be at least tacit public acceptance of the right of the VIA enterprise to use these waters.

National and supranational planners must confront this problem and devise ways to encourage the economic growth of large-scale VIA while protecting the environment and considering the rights of competitive uses of the waters.

Incentive programmes in the form of tax abatement and duty-free imports are often offered by developing countries to pioneer industries, such as VIAs. However, the incentive programmes initiated to attract investment do not ensure freedom from the imposition of restrictive laws, such as limiting percentage of foreign equity participation, currency convertibility, staffing patterns and labour costs. Doing business in certain societies requires industry participation in many social programmes, such as providing health care and housing and ensuring job security. These requirements may be viewed as a burden on a new enterprise, but they are part of the social, economic and political reality of the developing countries and must be judged in the context of the opportunity to make a significant contribution to both social and economic profit (Williams, 1975).

3.6 *Finance*

The economic scale of VIA business for profit is likely to be quite large, and the initial capital demand for land and improvements costs will be commensurately high. Without full recognition of the implications of these requirements, a major risk may lie in the failure to achieve the appropriate economic scale, and/or in being seriously undercapitalized. This matter was discussed above from the perspective of a problem area.

The high capital investment demanded by closed cycle systems of culture generally can be justified only when sites for more extensive systems are no longer available, and when the productivity is commensurate with high production costs, and when the products that are produced can demand high market prices.

The lack of hard data based on experience suggests that VIA is a high risk enterprise and many conventional sources of financing, such as commercial banks and even development banks, may not yet judge VIA ventures as bankable.

What may be required at the outset, therefore, is a number of pilot-scale aquafarming operations conducted in various environments, employing various culture techniques to grow out the several most promising candidate species. Thus, we can generate sufficient hard data for commercial and development banks and to allay their lack of confidence in the credit worthiness of VIA. Only then will the financial community make available a broad enough credit to support popular commercial aquaculture.

We judge the construction and operation of one or more aquacultural pilot farms to be in the public interest as well as in the private sector interest. This responsibility may require society at large, through governmental agencies, such as national banks and the national scientific community, in conjunction with private investors to share the risks and confront the problems of an incipient large-scale VIA industry. One such mechanism may be through subsidies which contribute to the support during the learning curve, but which are scheduled to sequential withdrawal as this important food resource matures into a self-sufficient industry.

Aquaculture as a VIA industry has only recently received the attention from experienced business managers and technologists that so complex a system of interacting variables requires to be integrated into a manageable diversified enterprise. It is just now in effect emerging from the conceptualization phase into the stage of critical pre-investment feasibility studies and detailed analyses which can lead to commercial implementation, and to ultimate social and economic benefit.

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Development of Vertically-Integrated Fish Farming in Europe

T. J. Cracknell

Abstract

In general, vertical integration can be justified only if it enhances the efficiency of the industry and, hence, the returns of its investors: the test seems to be how far such integration is 'natural' in that it links operations with similar management skills and between which lack of co-ordination is wasteful.

Four operations can be embraced in a totally integrated fish farming business: (*i*) supply of materials and services, (*ii*) farming itself (*ie* breeding and growing), (*iii*) processing, and (*iv*) distribution and final sales.

Aquaculture is essentially farming, not an extension of fish hunting, and it is often difficult for 'fish hunters' to understand the fish farmers'

concern with veterinary standards, feed conversion, *etc*. Administrators should not miss the opportunity to integrate fish farming with existing activities of agricultural communities.

Chicken meat production, a highly integrated industry, is frequently cited as a model for the development of fish farming. In the UK all the leading groups have achieved sufficient operation integration to obtain the planning advantages that this offers. Processing has now become the dominating co ordinating stage in integrated industries such as the British chicken industry. It is anticipated that the fish farming industry will follow this pattern and take for its model those organizations which undertake co ordinated distribution and marketing.

Scope for integration of fish farming will be influenced by: (*i*) the state of technical development, (*ii*) the requirements, and (*iii*) the capital intensity of the methods used.

Many concerns investing in fish farming are in industries which supply fish farmers. Suppliers see an opportunity for their products to be stimulated by forward integration into farming, but European feed suppliers are not attempting to combine farming and third party feed supply.

The forces toward integration are stronger for fish farming than for any other livestock farming and integrated concerns will develop in many sectors of the industry. This integration will be most marked in countries like the UK where retail buying power is concentrated in the multiple chains. It will be most marked for species such as marine finfish, where methods are technically new and capital intensive. With established farm species like carp and mussels there is no reason to see major change.

Two factors will limit the integration of ownership: (*i*) desire of owners of good sites to operate independent farms, and (*ii*) attitude of politicians who wish to see fish farming restricted to independent family farms.

L'évolution en Europe de la pisciculture verticalement intégrée

Résumé

De manière générale l'intégration verticale ne se justifie que si elle permet d'accroitre l'efficacite de l'industrie et, partant, les revenus des investisseurs: le critère semble être la mesure dans laquelle cette intégration est 'naturelle', c'est à dire associe des operations qui exigent des capacites de gestion analogues et où un manque de coordination serait source de gaspillage.

L'intégration totale d'une entreprise de pisciculture fait intervenir quatre séries d'opérations: (*i*) fourniture de matériel et de services, (*ii*) pisciculture proprement dite (a savoir reproduction et elevage), (*iii*) transformation, et (*iv*) distribution et commercialisation.

L'aquaculture est essentiellement une activité d'élevage et non un prolongement de la capture de poissons, et il est souvent difficile aux 'pêcheurs de capture' de comprendre l'interêt que les pisciculteurs manifestent a l'égard des normes véterinaires, du taux de conversion des aliments, etc. Les administrateurs ne devraient pas laisser échapper les occasions d'intégrer la pisciculture avec les activites habituelles des communautés agricoles.

La production de poulets de chair, activité hautement intégree, est souvent cite comme un modèle pour le developpement de la pisciculture. Au Royaume Uni, toutes les grandes entreprises avicoles ont réalisé une intégration de fonctionnement suffisante pour bénéficier des avantages de la planification. La transformation est désormais la plus importante etape de coordination dans les entreprises integrées comme les élevages britaniques de poulets. On prévoit que la pisciculture suivra cette orientation et s'inspirera des organisations qui ont entrepris de coordonner les opérations de distribution et de commercialisation.

L'integration de la pisciculture sera influencée par: (*i*) le niveau des progres technologiques, (*ii*) les besoins, et (*iii*) le capital qu'exigent les méthodes employées.

De nombreuses industries qui sont des fournisseurs des pisciculteurs s'intéressent aux investissements dans ce secteur. Elles voient dans une integration plus poussée avec la pisciculture une possibilité de renforcer l'utilisation de leurs produits, mais les fournisseurs européens d'aliments pour poissons n'envisagent pas de combiner pisciculture et fourniture d'aliments pour poissons en une opération triangulaire.

Les forces qui poussent à l'intégration sont plus vigoureuses dans le domaine de la pisciculture que dans tout autre forme d'élevage et des entreprises intégrées se créeront dans de nombreuses branches de l'industrie. Cette intégration sera particulierement marquée dans des pays comme le Royaume-Uni où le pouvoir d'achat au niveau du détail est concentré dans les chaines multiples. Elle sera entrêmement importante dans le cas d'espèces comme les poissons de mer qui exigent des méthodes techniquement nouvelles et beaucoup de capitaux. Aucune grande transformation n'est à prévoir avec les espèces d'élevage traditionnelles telles que la carpe et la moule.

Deux éléments limiteront l'intégration au niveau de la propriété: (*i*) le désir des propriétaires de bons sites de les exploiter de façon indépendante, et (*ii*) les pressions politiques visant à restreindre la pisciculture à des exploitations familiales autonomes.

Desarrollo de la piscicultura integrada verticalmente en Europa

Extracto

En general, la integración vertical está justificada sólo si aumenta la eficiencia de la industria y, por tanto, los beneficios de los inversionistas: el criterio decisivo parece ser en que medida la integracion es 'natural' es decir, vincula operaciones que exigen tecnicas de gestion analogas y en las cuales la falta de coordinación se traduce en un despilfarro.

Una empresa piscicola plenamente integrada puede abarcar cuatro operaciones: (*i*) suministro de materiales y servicios, (*ii*) piscicultura misma (es decir, la produccion y cria), (*iii*) elaboración y (*iv*) distribucion y venta final.

La acuicultura es esencialmente una actividad de cultivo no una extension de la caceria de peces, y a menudo a los "pescadores" les resulta difícil entender la preocupación de los piscicultores por el estado sanitario de los peces, la conversión de alimentos, etc. Los responsables de la administración pública no deben desperdiciar la ocasion de integrar la piscicultura con las actividades ya existentes de las comunidades agricolas.

La producción de carne de aves de corral, industria altamente integrada, se cita con frecuencia como modelo para el desarrollo de la piscicultura. En el Reino Unido, todos los grupos principales han conseguido una integracion de las operaciones suficiente para obtener las ventajas de planificacion que la integración permite. En las industrias integradas, como la industria avicola britanica, la elaboracion ha pasado a ser hoy la fase predominante de coordinacion. Se prevé que la industria piscicola se ajustara a ese esquema y tomara como modelo las organizaciones que realizan la distribucion y el mercadeo en forma coordinada.

En las posibilidades de integracion de la piscicultura influiran: (*i*) el grado de desarrollo tecnico, (*ii*) las necesidades y (*iii*) el coeficiente de capitalización de los métodos utilizados.

Muchas de las empresas que invierten en piscicultura son industrias que abastecen a los piscicultores. Los abastecedores ven en la integracion con la piscicultura una oportunidad de dar salida a sus productos, pero los abastecedores europeos de piensos no se esfuerzan por combinar la piscicultura con el suministro de piensos a terceras partes.

Las fuerzas favorables a la integracion actuan con mayor fuerza en la piscicultura que en cualquier otro sector pecuario y en muchos sectores de la industria surgirán empresas integradas. La integracion sera más acentuada en paises como el Reino Unido, donde el poder de compra al por menor está concentrado en cadenas multiples y afectará sobre todo a aquellas especies, como los peces marinos, en cuya cria se utilizan metodos tecnicamente nuevos y un coeficiente de capitalizacion elevado. C'on las especies piscicolas ya afianzadas, como las carpas y los mejillones, no hay razones para que se produzcan cambios importantes.

Dos factores limitaran la integracion de la propiedad: (*i*) el deseo de los propietarios de buenos emplazamientos de administrar granjas independientes, y (*ii*) la actitud de los politicos, que desean restringir la piscicultura a granjas familiares independientes.

1 Introduction

This paper provides a personal view of how vertically integrated concerns will feature in the development of fish farming in Europe. It is a view built up during two years spent setting up such a business and being involved in the organization of the UK fish-farming industry. The impressions and examples are slanted toward the situation in the UK, and some of the observations on activities elsewhere in Europe are based on reports rather than direct inquiries.

2 What to integrate—and why!

2.1 *Operations that can be integrated*

Fig 1 shows the operations which could be embraced in a totally-integrated fish-farming business. Four elements can be distinguished: (*i*) supply of materials and services; (*ii*) farming, *ie*, breeding and growing (*iii*) processing; and (*iv*) distribution and final sales. Factors influencing the tendency to integrate breeding and growing are examined in section 5, and integration forward into distribution and backward into supply are covered in sections 6 and 7 respectively.

2.2 *Is integration worthwhile?*

A strategy of vertical integration can only be justified if it enhances the efficiency of the industry and hence the returns of its investors. There is no automatic case for integration; no fundamental law that says that it is a good thing.

Economic texts stress the securing of sources of supply

and market outlets as the prime drive toward vertical integration. However, there are abundant examples where such integration has been no more than a strategy of despair by concerns finding themselves unable to increase their share of existing markets.

Analysts argue that market-related horizontal integration has been a more successful route to growth. By extending the range of goods and services offered to a single market place, concerns can exploit their established commercial skills, whereas vertical integration often takes the cobbler far from his last. We should question whether vertical integration in stock-rearing businesses like fish farming does lead to increased effectiveness, or whether it merely satisfies the operator's ambition to expand and the national planner's search for tidy structures to direct.

The test would seem to be how far such integration is 'natural' in that it links operations with similar management skills and between which a lack of co-ordination is wasteful. Vertical integration gives scope for centralized planning, but it takes away the competitive pressures and flexibility which comes from market forces operating at the interface between the stages of an industry. One must distinguish between integration where all the operations are in common ownership and those where contractual arrangements are set up to give the benefits of co-ordinated planning, but where no links of ownership exist.

3 Aquaculture—fishing or farming?

Before looking at what is the 'natural' level of integration, it is appropriate to consider whether fish farming is an extension of fish hunting or whether its roots lie in stock farming. It is submitted that the skills and attitudes needed to farm fish are those of the stock farmer not the hunter, and that it is important for the development of the fish-farming industry in Europe that its farming nature is recognized.

3.1 *Farmers, not fishermen, are becoming fish farmers*

The farming nature of fish culture is reflected by the

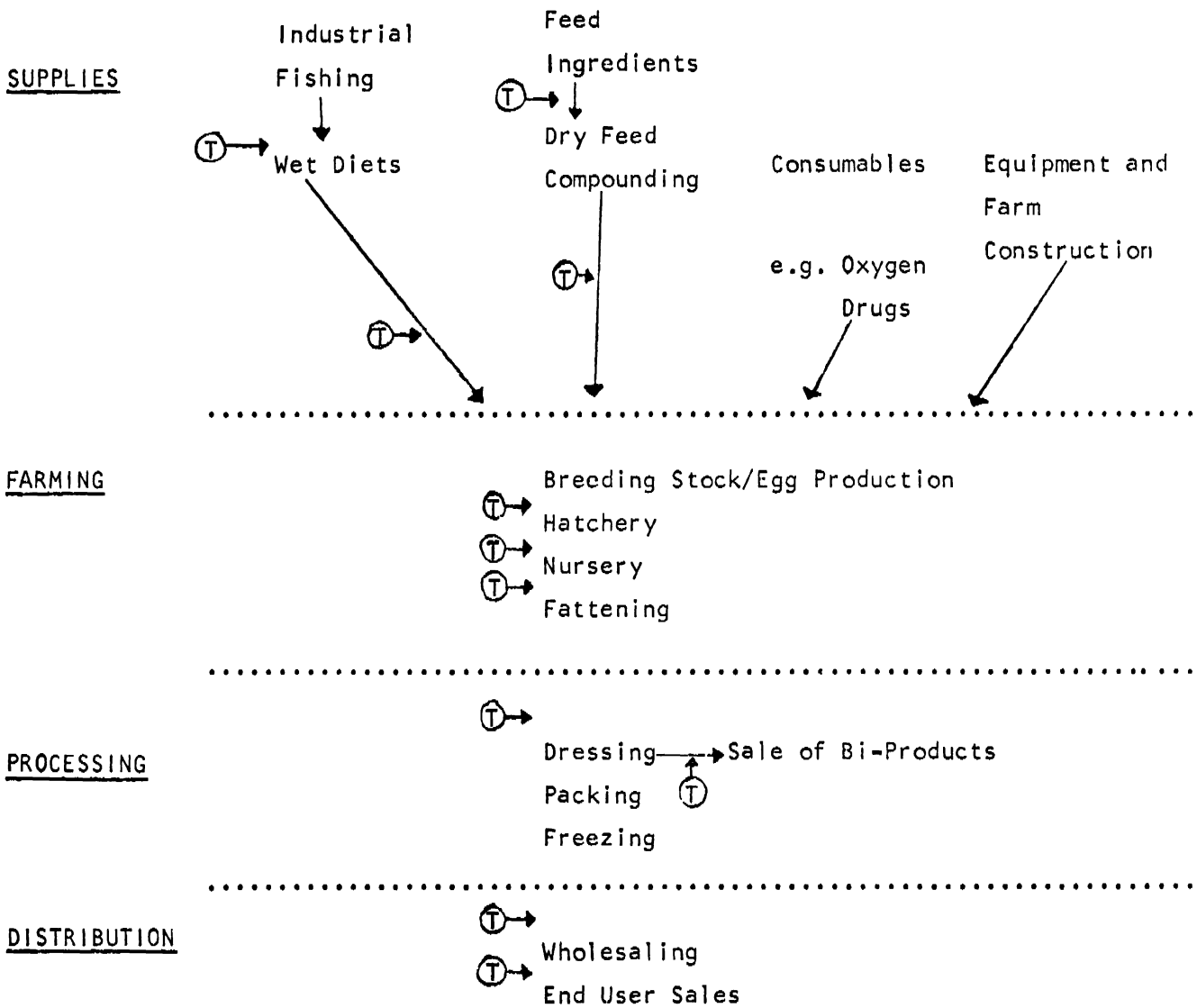


Fig 1. Operations in a totally integrated fish-farming business

numbers of individuals and firms with interests in livestock farming who are investing in the industry. This is to be expected with established freshwater species such as carp (*Cyprinus carpio*) and trout (*Salmo* sp.) which still account for 99% of European finfish production. Landowning farmers are in an advantageous position to develop suitable waters. However, 'farming' concerns are also the investors in major innovative projects. Corporations investing in fish farming in the UK include Fitch Lovell, Unilever, Rank Hovis McDougall, Booker McConnel, Shell and Fisons, all of whom have agricultural interests.

Fishing communities are active in the 'natural feed' shellfish industries, such as Spanish mussel farming and French oyster growing, which represent an intermediate between hunting and farming methods which use controlled feeding. In contrast, fish hunters are conspicuous by their absence from developments in controlled feeding approaches. Crivisa, the Spanish salmonid farmers owned by the fishing company Pleamar, appear to be the only exception.

Many of those involved in fish hunting in Europe are openly cynical about fish culture. Those committed to farming fish wonder whether this is because the hunters are preoccupied with the economic pressures they face or whether they know something not known to aquaculturists. Possibly their attitude is another example of reluctance to acknowledge the threat of a substitute produced by an unfamiliar technology. Perhaps the lack of interest by fish hunters in fish culture is just an acknowledgement that hunting and farming do require different skills and attitudes, and hence they are not 'naturally' integrated?

3.2. *Administrative consequences*

Many of those involved with the administration of fish farming have a lifetime's experience in boat design and fishery conservation, *etc*, but they are obliged to make a total switch of attitudes to understand the farmer's viewpoint, with his concern about veterinary standards, feed conversion and stockmanship.

It will assist the development of European fish farming if Governments avoid the superficial convenience of tacking responsibility for fish culture onto fish-hunting administrators.

The EEC Commission sees fish culture as an alternative source of income for fishing communities which are being encouraged to lay up uneconomic boats. These social engineering objectives feature strongly in the Commission's directives. Natural feed methods such as shellfish grow-out and ocean release ranching seem particularly appropriate as a response to these social objectives. The Ile d'Huet project in southern Brittany is an interesting pilot for such operations. The local fishermen's co-operative has contributed to the funding and the fishermen themselves have built a hatchery to produce oysters and lobsters for restocking local coastal waters.

It is hoped that the administrators, by thinking of fish first and farming second, do not miss the chance to integrate fish farming with the existing activities of agricultural communities. Throughout history, communities have been either hunters or herdsmen — the roles do not easily mix. Will men who have spent their lives hunting the seas readily turn to husbandry? Perhaps fishermen's sons will become fish farmers more readily than their fathers.

4 The chicken industry—an example of integration

Chicken-meat production is frequently quoted as an example of integrated livestock farming and as a model for the development of fish farming. UK chicken farming is an example of a highly integrated industry. Its success can be measured by the increase in output from 25 million birds in 1955 to 330 million birds in 1973, during which time chicken meat prices were practically constant whilst the UK cost of living rose threefold. The question is, how far integration was a cause of this success? By 1974 the top ten organizations in this field accounted for over 70% of national production with the market leader, Ross, having a 22% share. Five of the top ten are now subsidiaries of major international companies and the remainder are independent groups built up by individual farmers and co-operatives. The management of the leading groups are committed to integrated operations. However, this philosophy is tempered by pragmatism and each company has a slightly different mix of activities under its own control. In many cases the continuing use of outside contractors derives from historical associations.

There is considerable trading between the top companies. Only Ross and Marshall have become involved with breeding stock, the remainder buying in birds from Ross and from specialist breeding companies such as Cobb and Hubbard.

Many of the specialist breeding companies are US based and illustrate a 'technology transfer' contribution of multinationals in this area of livestock farming.

Company owned hatcheries are seen by many as a cornerstone of integrated operations and yet Thornhill has opted against company-owned hatcheries and prefers to buy chicks in the open market. The trend to company owned sites contrasts with the USA, where much of the ongrowing is by small family operations contracted to the processors. The different US and UK approaches illustrate how cultural norms influence the balance of advantage between the motivation achieved by contracting out and the extra discipline of company-operated units. The organizational requirement of combining co-ordination with individual commitment is met in some European chicken industries, notably in Denmark, through producer co-operatives. This form of organization, which is the exception rather than the rule in British agriculture, has much to commend it for intensive livestock farming. Yet some observers question whether co-operatives, although ideal in established industries, permit sufficient flexibility for an industry which is growing rapidly or undergoing major change.

Another lesson from the chicken industry comes from examining how far the companies have integrated back into the supply of goods and services and forward into the market place.

The integrated concerns stress the importance of controlling their own feed supplies and most operate their own mills and reprocess offal through them. It is also considered vital to control the transport fleet which is the link between the stages of the integrated operation. Marshall is an example of a group which uses company owned vehicles for transporting feed ingredients, feed, chicks, birds for processing and processed products.

A number of the concerns even have timber construction subsidiaries which build their new chicken houses, although this is not seen as an essential element of an

integrated operation.

Many of the groups, for example, Union International and Fitch Lovell, have wholesaling subsidiaries operating in the traditional meat markets. In general, these trading activities were established many years before the integrated chicken operations developed. Diverse field groups like Fitch Lovell and Unilever also own supermarket chains but there is little management overlap and intra group trading is at arm's length. The conclusion from studying the UK chicken industry is that, whilst the degree of integration of ownership varies to some extent, all the leading groups have achieved sufficient operation integration that they can obtain the planning advantages that this offers. Whether such integration is likely to develop within fish farming is considered below.

5 Factors influencing the integration of fish-farming operations

The scope for integration of fish farming operations will be influenced by the following factors:

5.1 *The state of technical development*

A concern farming a species for which the basic culture methods are not established desires control of the whole farming operation from brood stock to fattening. Otherwise its own progress can be hamstrung by the failures of others to solve technical problems. Examples of European concerns working on all farming stages in order to provide technical completeness are Fitch Lovell's turbot (*Scophthalmus maximus*) programme and the sea-bass (*Dicentrarchus labrax*) operations being set up in the Mediterranean. Such research programmes covering all the farming stages, including nutritional work, are natural precursors of integrated industries.

Salmon (*Salmo salar*) and trout farming show a different picture. Key technical problems with salmon relate to the smolting, acclimatisation and seawater grow-out stages. With freshwater trout farming, grow-out is also the limiting stage of production, due to shortages of water of suitable quality. Establishments devoted to sport fishing and restocking of natural waters have been working on the hatching and early rearing of salmonids for decades. Hence, there is a greater incentive for those concerned with grow-out to draw stocks from a number of egg and fry suppliers and there is less competitive advantage in monopolizing quality supplies of juveniles. Also separate stations are needed for fresh and salt-water stages, and hatcheries and freshwater grow out units have differing water requirements. These reasons have resulted in specialist juvenile producers setting up in the major salmonid industries.

5.2 *Site requirements*

With some fish farming methods, particular locations provide an ongoing cost advantage, *eg*, in the use of large springs for salmonid hatcheries. With other operations the number of possible sites is strictly limited. For example, smolting stations require supplies of both fresh and salt water of good quality; and at most accessible river mouths in Europe communities have developed, making the sites unsuitable for fish farming. In these situations vertical integration under one ownership is complicated through the likelihood of the owner of each advantageous site wishing to farm fish independently or at least expecting a financial involvement in the integrated project. Such difficulties of establishing rights to develop particular sites relate not only to the farm site itself, but also to site access where this involves rights of way controlled by others. Difficulties of access have also arisen with some foreshore shellfish beds.

Such site limitations on the potential for integrated ownership are less with open-sea technologies such as cage culture, mussel rafts and yellow-tail enclosures. There is much greater flexibility of access to these facilities once ownership rights in the sea have been established.

5.3 *Capital intensity*

An impetus toward vertical integration in the chicken industry was the escalating capital requirements as methods became more industrialized. With capital intensive methods, the financial penalty for under utilization of plant can be crippling. This had led to pressures for integrated planning rather than dependence on the vagaries of the market.

The capital intensity of the methods used will similarly influence the level of integration in fish farming. Traditional pond culture methods have negligible fixed costs. Labour, as well as feed, is a truly variable cost for a farmer who can turn his attention to other crops when there are no fish to tend. Hence the penalty for under-utilization of ponds is inconsequential. In contrast, with intensive units, the aim is to reduce variable costs such as feed and labour and stock losses sufficiently to compensate for the fixed overhead incurred in providing operational control. In this case, a fall in tank utilization from 95 to 90% can make all the difference between attractive and not so attractive returns. This creates an incentive for the intensive unit operator to integrate backward in order to secure year round supplies of eggs and fry: a pressure not similarly felt by the pond culturist.

6 Integration of farming and marketing

Growing sophistication of food retailing, with amalgamations leading to fewer, more powerful buying points, has been a major force drawing stock farmers into integrated processing and distribution. Supermarket chain buyers want regular supplies meeting agreed specifications at a guaranteed quality. Their demands have led to processing becoming the dominant co ordinating stage in integrated livestock industries such as the British chicken industry. Similarly, processors of hunted fish have grown in importance at the expense of traditional markets which they frequently by-pass.

French and Danish trout farming illustrate the extremes in processing organization a reflection of the differing food distribution channels that they serve. There are French trout farms in almost every Departement. Practically all of the 16 000 tons they produce each year is sold unprocessed, much through local and regional markets. This fits with the French housewife's habit of buying meat and fish fresh at the market. On the other hand, the Danish industry is concentrated in a small area of Jutland and is geared to external markets, principally exports. In markets such as the Federal Republic of Germany and the UK there is demand for branded, dressed and frozen products. This has been efficiently met through forward integration into processing by farmers' co-operatives.

Centralized processing of all species of farmed fish will be the rule in countries such as the UK where retailing organizations are large and frozen food is widely accepted. This processing will be by fish farming concerns integrating forward and also, and more probably, by horizontal integration as fish processing companies widen their activities to cover farmed fish. It is understood that in Italy the integration has developed in the opposite direction, with fish-processing interests setting up some of the country's largest trout farms.

To the processor the critical difference between farmed and hunted fish is the controllability of supply. Supply of farmed fish should in due course be easier to regulate than that of farmed meats, due to the greater ability to speed up or slow down growth with a cold blooded animal. Even so, the fine balance between glut and shortage which so typifies agricultural markets will also exist for farmed fish, and calls for co-operation in regulating supply. Co-operation is not necessarily easier, however, when there is a handful of vertically integrated concerns fighting for market domination.

Whilst the development of freezing has reduced supply fluctuations, the structure and philosophy of hunted fish channels of distribution is still geared to day to-day matching of demand with varying supplies. It is anticipated that the fish farming industry will increasingly ignore these traditional distribution channels and take as its model the organizations which undertake co-ordinated distribution and marketing of farmed meats.

7 Integration forward by suppliers

Many of the concerns investing in fish farming are industries which supply fish farmers. The interest of suppliers is in marked contrast to the attitude of fish hunters. The psychology is different. The suppliers see an opportunity: a new application for their products which they choose to stimulate by forward integration into fish farming. The hunters see a threat to which they react defensively.

Reference was made in section 3.1 to the number of farmers and landowners taking up fish culture to exploit the water which they control. Specialized examples of site owners entering fish farming are the Salt Company in southern France which experimented with culture in their salt pans, and the gravel companies in the UK whose farming activities in disused pits help to placate environmentalists critical of the extracting activities. Apart from suppliers of sites, suppliers of feed and equipment feature strongly in fish-farming developments.

7.1 *Feed*

The Danish trout industry provides a classic example of integration back into feed supply. The Farmers' Co-operative has linked up with near-water industrial fishing boats to provide the trash fish diet traditionally used on Danish farms. It is widely accepted that this integrated operation has been a key feature of the success of the Danish industry over the last 25 years. The Farmers' Co-operative has also acquired Clark, the trout pellet compounders. This gives them control over both wet and dry feed supplies.

The proprietary dry fish feeds in Europe are all for salmonids, principally trout. A number of feed suppliers were established compounders who extended their product ranges to include salmonid pellets, *eg*, Cipasa and Bioter in Spain and Skretting in Norway. The other major groups of fish feed companies are specialist ingredient suppliers who, by moves which can be classified as forward integration, have become involved in fish feeds. The leading illustration is Sterling H. Nelson, the Utah based ingredients factory which entered the US trout-feed market with the brand Silver Cup. Licensees of Silver Cup operate in each of the major European trout markets. Astra Ewos, Sanders, Trou and Cooper-Zeltia, are amongst the leading salmonid feed companies and are also offshoots of organizations involved in speciality feeds, supplements and concentrates or veterinary chemicals and pharmaceuticals. Such concerns are geared to the high margin, low volume technical marketing needed to pioneer new specialist feeds. The question is whether the speciality companies will make way for the national compounders or will fight to maintain their market position in fish feeds. Either way the European fish farmer stands to gain. Increased competition among feed suppliers will reduce the incentive for fish farmers to integrate back into feed production in the way that the Danish Trout Farmers' Co-operative have.

BP Proteins acquired control of Trou, Jouet and Cooper, making them by far the largest European fish-feed suppliers. BP's investment in fish feeds, which is reputedly to establish a market for their single-cell proteins, is another example of forward integration by a supplier seeking a product application opportunity. Feed suppliers are not increasing their direct involvement in fish farming. None of the companies are attempting to combine farming and third-party feed supply as are Ralston Purina in the US catfish industry. The general view is that it is not practical to compete with one's customers in a developing industry such as fish farming.

7.2 *Equipment and consumables*

Two of the significant investors in European fish farming are BOC and ITT. The interest of both has come through the technical significance of their products to fish farming. As an international industrial gas supplier, BOC's starting point is to ask why fish farming should be limited by water supplies when the water is little more than a carrier for available oxygen. ITT's entré has been through their Swedish pump subsidiary Flygt and is drawing on the group's know how in environmental control and water treatment. Hardly surprisingly, both these companies are concentrating on the development of intensive water-saving farming methods. Astra-Ewos and Skretting supply fish-farming equipment as well as feed. Marketing of these two groups of supplies is complementary and the example of these companies can be expected to be repeated in other markets.

8 Conclusions

Questions that can be asked are: (*i*) what is the 'natural' level of integration in fish farming? and (*ii*) what is the balance of the forces leading toward or away from the development of vertically-integrated concerns?

It is the author's assessment that the forces toward integration are stronger for fish farming than for any other type of livestock farming and that integrated concerns will develop in many sectors of the industry.

Integration will be most marked in countries like the UK, where retail buying power is concentrated with

multiple chains. It will be most marked for those species, such as marine finfish, where farming methods are technically new and capital intensive. With established farming species like carp and mussels, there are no reasons to see major change from the present mix of integrated and independent operations.

There are two influences which will limit the integration of ownership. The first will be the desire of owners of good sites to operate independent farms. The second and less easy to forecast influence will be the attitudes of politicians who in some parts of Europe are keen to see fish farming restricted to independent family farms.

The Status of Vertically-Integrated Aquaculture Industry in the United States

P. Briggs

Abstract
Industrial organizations, including those concerned with aquaculture, are generally moving toward vertical integration, *ie*, toward the control of almost all facets of product development and marketing. Such integration often lessens the impact of cyclical economic fluctuations and improves the quality of the product at all stages. It is usually associated with large economic units, large production, large markets, and large profits.

With respect to aquaculture, a vertically integrated industry is one in which the owning, managing or controlling company controls: hatching operations, grow out operations, manufacture of feeds, processing and marketing of the product.

Within the USA, trout, oysters, catfish and exotic fish producers do not, in general, have a very high degree of vertical integration. The baitfish and crayfish industries, although small, are highly profitable and integrated. The highest degree of vertical integration has been achieved by the Pacific salmon and shrimp culturing industries which are tending to be dominated by a relatively small number of companies which are, in turn, owned by larger corporations having goals of extremely large markets.

Many factors favour the formation of vertically integrated aquaculture industries, and most aquacultural industries lend themselves to this type of organization which, promotes research and large scale technology, induces large capital investment, utilizes team organization and assists product development and marketing.

Various 'climates' in the USA – social, economic and governmental – all favour the continued development of vertically integrated aquaculture. Small cottage type aquacultural businesses will persist but large multi-national companies with enormous annual sales will play a key role in the industry.

Etat de l'industrie aquicole pratiquant l'intégration verticale aux Etats-Unis
Résumé
Les organisations industrielles, y compris celles qui s'occupent d'aquaculture évoluent généralement vers l'intégration verticale, c'est à dire vers le contrôle de la quasi-totalité des aspects de la mise au point et de la commercialisation des produits. Une telle intégration atténue souvent l'influence des fluctuations dues aux cycles économiques et améliore la qualité du produit a tous les stades. Elles est d'ordinaire associée à des unités économiques plus vastes, a une production plus elevée, à des marchés plus importants et à des profits plus considérables.

Du point de vue de l'aquaculture, une industrie intégrée verticalement présente les caractéristiques suivantes: une societe a la haute main sur la propriété, la gestion et le contrôle (opérations d'alevinage; engraissement; fabrication des aliments, traitement et commercialisation du produit).

Aux Etats Unis, les producteurs de truites, d'huitres, de poissons chats et de poissons exotiques n'atteignent pas en général un degré élevé d'intégration verticale. Par contre, les industries des poissons d'appât et des crustacés, bien que petites, sont hautement profitables et tres intégrées. Le degré le plus poussé d'intégration verticale a été réalisé par les industries qui pratiquent l'élevage des crevettes et du saumon du Pacifique; elles tendent en effet à être dominées par un nombre relativement restreint de sociétes qui, à leur tour, appartiennent à de plus grosses firmes qui s'intéressent à des marchés extrêmement vastes.

De nombreux facteurs favorisent l'intégration verticale des industries aquicoles et la plupart de ces industries se prêtent à ce type d'organisation qui a les avantages suivants: elle favorise la recherche et développe la technologie, stimule de gros investissements de capital, recourt à une structure spécialisée et encourage la mise au point et la commercialisation des produits.

Le climat américain—que ce soit du point de vue social, économique ou governemental—favorise l'expansion constante de l'intégration verticale en aquaculture. Les petites affaires aquicoles du type artisanal persisteront, mais les grandes sociétés multinationales dont les ventes annuelles sont énormes joueront un rôle déterminant dans cette industrie.

Situación de la acuicultura integrada verticalmente en los Estados Unidos
Extracto
Las organizaciones industriales, incluso las que se ocupan de acuicultura, tienden en general a la integración vertical, es decir, a controlar la mayoría de las facetas de el desarrollo y mercadeo del producto. Con frecuencia, esa integración reduce el impacto de las fluctuaciones económicas cíclicas y mejora la calidad del producto en todas sus fases. Esta es generalmente asociada con grandes unidades económicas, gran producción, grandes mercados y grandes beneficios.

En el campo de la acuicultura, una industria integrada verticalmente es aquella en la que la empresa propietaria o administradora controla los trabajos de incubacion, las actividades de cria, la fabricación de piensos, y la elaboración y mercadeo del producto.

En los Estados Unidos, los productores de truchas, ostras, bagres de canal y peces exóticos no han alcanzado, en general, un grado muy elevado de integracion vertical. Las industrias de peces para cebo y cangrejos, aunque pequeñas, son altamente rentables y estan integradas. El máximo grado de integración vertical lo han conseguido las industrias de cultivo de salmón del Pacifico y camarones, sector que tiende a estar dominado por un numero relativamente pequeño de empresas, que, a su vez, son propiedad de corporaciones mayores que tienen como objetivo cubrir mercados extremadamente vastos.

Muchos factores favorecen la formacion de industrias acuicolas integradas verticalmente, y la mayor parte de las industrias de acuicultura se prestan a esta clase de organización, que favorece las investigaciones y el empleo de tecnologia a gran escala, atrae grandes inversiones de capital, se sirve del trabajo en conjunto, y facilita el desarrollo de nuevos productos y su mercadeo.

Varios 'climas' de los Estados Unidos – sociales, económicos y gubernamentales – favorecen el continuo desarrollo de la acuicultura integrada verticalmente. Las pequenas empresas acuicolas de tipo familiar seguirán existiendo, pero las grandes empresas multinacionales con ventas anuales enormes desempeñarán una función clave en esta industria.

1 Introduction

The history of the industrial revolution is primarily built around a number of technological inventions which resulted in the formation of large corporations to exploit these inventions economically. Most of the corporations so formed have become totally vertically integrated and are now organized on a multi national basis. Vertical integration is a common characteristic of most of the successful large companies in those industries which are oligopolistic in character.

1.1 *Vertically integrated industry*

In the field of aquaculture, a vertically integrated industry is one in which the owning, managing or controlling company controls the hatching operations, grow-out operations, manufacture of feeds, processing capability and marketing of the product. Totally vertical integration might be interpreted as control of the product clear through to sale to the final consumer, but in most cases the marketing function stops short of that; *ie*, the product is sold at the wholesale or retail level. It still, however, attains most of the advantages of totally vertical integration.

1.2 *The concept*

There is a latent force in industrial organizations moving them toward vertical integration. This force can basically be described as a need to control, as much as possible, all facets of product development. One reason for the wide spread development of vertically integrated industries is the fact that if the price goes up after a product has been sold to the next level, in a vertically integrated industry, the sudden loss or profit—as the case may be —can then be spread over the different increments of product development thus lessening the impact of cyclical economic fluctuations. Another reason is that when different levels are broken up into different proprietary interests (for example, when an independent producer sells to an independent processor) the producer has little interest in the quality of the product: whereas in a vertically integrated industry the controlling interest is concerned with quality throughout the process. Implicit in the trend toward vertical integration is the concomitant trend toward bigness; the more successfully an industry is integrated the more large companies it will have.

Most of the larger companies which go into the field of aquaculture aspire to ultimately control all aspects of product development of the particular species with which they are engaged. For example, the Pacific salmon industry has seen a number of companies acquired and merged into larger corporations. The commercial catfish farming industry is another example where consolidation has begun. It has, however, been less predominant because of the key role of the farmer himself and the fact that most catfish farmers are, by experience, farmers of row crops who have historically not lent themselves to vertical integration except through the use of co-operatives. The trend has also been less predominant in the trout farming industry.

2 Present status of vertical integration in aquaculture

Probably the most parallel example of an industry compared to aquaculture is the poultry industry. In this field, there are companies which hatch and grow their own product, produce their own feed, process and market the product with a brand name in retail stores and through fast-food restaurants where virtually all of the birds sold have been produced by the company. With this in mind, let us examine the principal aquaculture industries in the United States with significant commercial activity: trout, shrimp, oysters, catfish, crayfish, salmon, baitfish and exotic fish.

2.1 *Trout*

In the trout (primarily rainbows, *Salmo gairdneri*) industry, there is little complete integration because most producers purchase feeds from companies specializing in the manufacture and sale of trout feeds. Many producers also buy the juvenile stock from other producers who specialize in trout spawning. Other than this, most producers grow-out their own fish, process them and market the product. The method and type of sale and marketing effort depends upon the volume of production. Smaller producers will typically market their product within close range of the processing area. Larger producers, concentrated primarily in Idaho, sell their product throughout the United States. The future of this industry will probably see the continuing situation with ten to twenty per cent of the trout production produced by cottage-type businesses with the largest dozen trout-producing facilities being further reduced in number through mergers and acquisitions.

2.2 *Shrimp*

At this time, there are no companies known to be operating shrimp production facilities at a profit in the United States or Central America. However, it does appear that within one to three years, a number of companies will probably cross the break-even point and begin to operate at an economic profit. Most of the companies in the industry plan substantial vertical integration, and in the intermediate to long-range future we shall see most of the major shrimp culturing companies totally integrated. Furthermore, they will probably be owned by large corporations who will have goals of a forty or fifty million dollar market for shrimp. A company in excess of a thousand million dollars must develop a facility generating at least forty to fifty million dollars before it becomes a worthwhile undertaking.

2.3 *Oysters*

Within the oyster industry in the United States, some companies have full control of all the processing, *eg*, a private planter will collect or buy the seed, raise the product, shuck it, and sell it at wholesale, or retail to the consumer. There are a number of examples of this process within smaller oyster companies. On the other hand, there are some that do as little as buy seed, plant it and then have somebody else harvest the product. Most oyster companies on the west coast control the process through harvest and shucking. After shucking, most of the smaller or medium sized companies will sell the product, usually to a marketing group. Until recently, there was a United Marketing Co operative for oysters, and more recently, Coast Oyster Company became large enough to dominate the industry. Most of the smaller companies now sell through its marketing organization. Again, they are not completely vertically integrated they are integrated only up to the point where they have shucked the product and put the product into Coast Oyster Company jars. There are others that can the product and sell it at that point on a distributor basis. It may be that some of the smaller companies tend to be vertically integrated in that they carry their product through to sale to a retailer or in some cases directly to the consumer. The large companies tend to be integrated up through the production of a product but not generally as far as marketing. The marketing follows the pattern of most other canned or processed food products.

2.4 *Catfish*

The catfish (channel catfish, *Ictalurus punctatus*) farming industry is not characterized by vertically integrated operations. There are two companies which are substantially vertically integrated. Farm Fresh Fish and ConAgra. Each of these spawns, grows-out and markets the fish. They buy their feed, however, from independent feed-manufacturing companies, and also purchase a large portion of the fish which they process from independent producers. Most of the industry is characterized by free-standing producers who manage their own grow-out operations and, in a number of cases, also spawn and grow their own fingerlings. There are a number of farmers who have fingerling operations exclusively and who market their fingerlings to other grow-out operators. There are perhaps ten companies marketing substantial quantities of feeds to the industry. There

are four major processors who maintain significant process ing and marketing operations. All the processors maintain their own marketing arms.

In the future, it appears that the farmers will continue to produce the large majority of the catfish independently with little vertical integration. A number of farmers have organ ized a feed co-operative, with headquarters in Belzoni, Mississippi, and managed by the Mississippi Federated Co-ops, a major agricultural organization which provides management for varied types of farmer co operatives. The catfish industry is beginning to reach maturity. There are fewer and fewer producers but these produce an increasing quantity of product in a more efficient fashion. The industry is growing primarily as a result of increasing efficiencies but it does not appear that there will be increased vertical integration.

2.5 *Crayfish*

In the crayfish (*Procambarus*) industry, a unique aquaculture venture, practically all the producers are substantially integrated. The industry is relatively small. Because of its unique features, it does not appear that this industry will change significantly in its manner of organization. Most of the product is produced by relatively small producers and will so continue.

2.6 *Salmon*

The salmon industry, which cultivates Pacific salmon (*Oncorhynchus*) stocks, is becoming more and more vertically integrated; the trend is toward a relatively small number of highly integrated companies. Two production methods are used: pen rearing and ocean ranching. Both methods lend themselves to vertically integrated operation. Only one of the producers now produces its own feeds; however, several larger companies will probably begin to produce their own feeds when they reach significant volumes. Moreover, most of the companies producing salmon now use outside processing and marketing facilities but, as volume becomes significant, it is anticipated that the larger producers will process and market their own product. As mentioned before, the trend toward merger and acquisition is manifest in the salmon industry with purchases of small operations by Weyerhauser and Union Carbide, two giant companies involved in the salmon industry. It appears that there will be a place in salmon culture for small producers who have freshwater facilities. They may raise a million pounds of salmon and sell it to a larger integrated company which will raise them in salt water.

2.7 *Baitfish industry*

Although the baitfish industry is not significant on a national scale, it is a highly profitable and very integrated aquaculture industry. The baitfish farmers are, in most cases, highly integrated except for production of feeds.

2.8 *Exotic fish*

The exotic or ornamental fish industry is similar to the catfish industry in that most of the producers hatch and grow out their own product and use feeds manufactured by companies specializing in feed production. Many of the exotic fish producers market their own product; others sell to other marketing organizations. There is no processing sector of the exotic fish industry.

3 Major problems of vertical aquaculture

Aquaculture appears to have an important future. There are, however, a number of trends in the food industry and in the demand for protein which will have a substantial impact on certain aspects of the commercial aquaculture industry as we know it in developed countries. It is difficult to predict the impact which these developments will have on aquaculture until one can assess the impact on society as a whole.

3.1 *The need for large economic units*

If aquaculture is to develop, significant amounts of resources must be invested; these will come from two basic sources: government and private industry. The budget pressures on governments, at all levels and throughout the world, are such that it is not anticipated that investments of the required magnitude will come from them, except with respect to certain species where short-range results can be expected. Private industry will, therefore, play a significant role in the development of aquaculture. Private industry will invest the funds necessary to develop a species for commercial purposes only if it can be developed to realize profits large enough to interest an investing company. Most of the companies able to invest the amount needed to develop economically viable enterprise— estimated to be between one and twenty million dollars (depending on the species and the level of technological evaluation), are in excess of a thousand million dollars in size. Companies of such size are not interested in developing ventures unless they will ultimately produce forty to fifty million dollars in gross sales annually. At this time, the companies which are investing in the aquaculture industry on such a scale are investing significant amounts in anticipation of reaching an economic break-even point within a five-year period. If these companies do not succeed, it could result in a major step backward for all areas of aquaculture. Losses in the catfish farming industry have already led to a severe backward step in commercial aquaculture.

3.2 *Fossil fuel dependence of aquaculture*

In the United States (and other developed countries) most aquaculture activity is dependent upon fossil fuel and fossil fuel derivatives. It is anticipated that fossil fuels will continue to increase in price probably faster than the declining value of the American dollar, which will result in cost increases in the commercial aquaculture field at rates higher than the cost of living index.

3.3 *Need for protein sources for feeds*

The impact of the Peruvian anchoveta shortage in 1972 was felt throughout American agriculture and had a particularly significant impact on animal production, including that of cultivated fish. The demand for protein will continue to increase, and as the rate of increasing supply slows down, it is anticipated that the cost of all protein will increase. Since most aquaculture depends on protein-based prepared feeds, we shall see an increase in cost of fish feeds. Such a liability may, however, be an asset of aquaculturists in that fish are generally more efficient converters of food than most domestic animals.

3.4 *High consumer cost of species being developed*

Another factor inhibiting the development of aquaculture and its vertical integration is the fact that most fish products

now being developed are highly expensive. This is, however, only a short- to intermediate-term problem because as food prices increase the consumer will turn to alternative sources of cheaper food. It can be anticipated, therefore, that commercial aquaculturists will (in addition to continuing with already established markets for high cost items), turn their expertise to other species which can be cultured at less expense. One example is common carp (*Cyprinus carpio*) which most American consumers do not consider to be palatable; another is milkfish (*Chanos chanos*) as cultivated in the Philippines, Indonesia and elsewhere.

3.5 *Limited experienced management*
Another limiting factor in the development of vertically integrated aquaculture is the amount of management expertise available. It is estimated that in the United States there are less than a thousand highly qualified commercial aquaculturists. There are probably an additional twelve to fourteen hundred aquaculturists who have competence but are not highly skilled and experienced managers.

3.6 *Limited uses for offal*
A minor problem inhibiting the development of vertically integrated aquaculture industry is the limited use for waste products or offal. It is anticipated that as the volume of offal increases, more uses will be found for it, demand for it will increase, and the problem will substantially be solved.

4 Factors which favour the formation of vertically integrated aquaculture industries

In spite of the aforementioned problems, the American industrial matrix contains so many successfully vertically integrated companies that, given the necessary technology, there is sufficient industrial creativity to develop a profitable vertically integrated aquaculture industry. The most promising indication of its bright future is the presence of major corporations who are already in the aquaculture field.

4.1 *Involvement of major corporations*
The major companies in the USA involved in the field of aquaculture and their total annual sales from all sources are listed below:

Company	*Species cultivated*	*Total annual sales from all sources US$*
Cities Service Oil	Crayfish and prawns	2 806 300 000
ConAgra	Catfish	633 644 000
Dow Chemical	Freshwater prawns	4 938 483 000
General Mills	Freshwater prawns	2 000 103 000
Lamont Corporation	Lobster and trout	413 584 000
Ralston Purina	Freshwater prawns	3 073 210 000
Syntex Corporation	Freshwater prawns	245 861 000
Union Carbide	Pacific salmon	5 320 123 000
Weyerhauser	Pacific salmon and shrimp	2 529 013 000

A large number of public utilities are growing different species in fresh water, but as yet none are making a profit.

4.2 *Interest of the business press*
Involvement of such large companies in aquaculture will draw the attention of the major business journals in the United States, *eg*, *Barrons*, *Business Week*, *Forbes*, *Fortune* and the *Wall Street Journal*, which are read by most major managers and investors. When such publications report on the participation of these companies in experimental projects such as aquaculture, this draws the attention of other investors which results in a ripple effect with consequent increase in the ability to finance new ventures. This interest will come from: corporations which invest and manage their own money, investment syndicates which invest in independent operations, and financial houses which assist experienced managers (in this case aquaculture managers) to secure new financing for a newly developing technology.

4.3 *The continuity of small producers*
There are four aquaculture industries (catfish, trout, crayfish and oysters) where small producers are producing and marketing a product at a profit. This provides assurance that, regardless of the short-run experience of the larger producers, the smaller producers will continue their operations as long as there is a reasonable demand for their product and they are able to secure a fair return. Smaller producers have the advantage of very limited overheads and no significant expenses for personnel. Many employ family members with all the income going to one family unit. These smaller producers sell their products at or near their production facility and through fee fishing operations, where appropriate.

4.4 *Inherent suitability for vertical integration*
Aquaculture is an industry which generally lends itself to vertical integration. Some of the reasons for this suitability follow:

(*i*) Aquaculture development requires large scale technology which requires vertically integrated major companies.

(*ii*) Aquaculture development requires skilled capital formation which in general will come from vertically integrated companies, rather than from governmental programmes.

(*iii*) Aquaculture product development requires a sustained and organized team effort, which functions best in a vertically integrated industry with regular and open interchange between the different segments of product development.

(*iv*) Aquaculture is still such a new field - with possibilities for large technological breakthroughs which can result in substantial profits—that corporate and financial developers are willing to take inordinate risks in the industry. As most of these investor developers equate successful large development with vertically integrated operations, this is another positive force for its establishment.

(*v*) As yet no substantial company holds a dominant position, either in size or technology, in the field of aquaculture. Therefore any one of a number of companies can emerge as the most successful in the field. The significance of the larger more profitable companies is that they often acquire the smaller ones and so maintain a greater control over the market, thus enabling them to further profit from successful vertical integration.

(*vi*) The need to have expertise in the production of various species is aided by a vertically integrated industry which is apt to possess such experience. As in most other industries, international market fluctuation and new technological discoveries may have a heavy impact on the field of aquaculture- even if they first appear to have no direct bearing on it. For example, when the price of petroleum rose and consumers travelled less, an unexpected demand arose for more long distance telephone services. A similar

scenario of aquaculture might go as follows: as food prices rise, the consumer will search for lower cost sources of protein. Heretofore, the American consumer has not eaten carp in large quantities. However, carp is easily cultured and a high level of technology exists in other countries where carp is widely cultured and enjoys extensive consumer acceptance. In response to a demand for this product, existing aquaculture management and technological expertise might be turned to the production of carp resulting in an increase in quantity and profitability of the operation. Integrated companies who now have catfish, bait-fish and in some cases, trout production facilities could conceivably convert to carp cultivation with increased profit.

5 The future of vertical integration in aquaculture

If there is to be significant increase in production of fish for human use through aquaculture in the United States there will be a concomitant increase in the vertical integration of the industry. The following predictions can be made.

(*i*) The development of vertically integrated aquaculture will vary directly with the involvement of large corporations in the field of aquaculture. Some of these corporations may be producer co-operatives and new corporations not currently involved in the field.

(*ii*) Further acquisition in the field of aquaculture will result in further vertical integration.

(*iii*) More companies will use hot water effluent as a by-product to produce fish. Most of these companies will initially limit their involvement to production. If their production becomes substantial and profitable, they will start vertical integration, and there will be a number of mergers. The remaining companies will be those with the highest level of management expertise and financial capitalization.

(*iv*) It is anticipated that the companies in the field of aquaculture in five to seven years will operate at a volume of between fifty and one hundred million dollars a year from aquaculture operations. They will be a part of a larger corporation, probably involved in unrelated business as its primary source of income.

(*v*) Vertically integrated operations will result in initially exponential increases in the efficiency of production which will then move to arithmetical increases and finally a plateau in developing efficiency of production.

(*vi*) As vertically integrated operations become established, they will uncover new species for production, and develop their production into commercial viability much more quickly than has been done in the past.

(*vii*) Vertically integrated operations will spend a significant part of their pre tax cash flow on further research to develop the culture of new species, increase productivity of present efforts and re-examine species whose use was once cast aside as not being economically feasible.

(*viii*) Vertically integrated industries will greatly enhance the level of research in genetics and nutrition in both the public and private sector.

(*ix*) Vertically integrated companies, as they reach maturity, will provide substantial levels of support for university and governmental research projects.

(*x*) The successful development of commercially profitable vertically integrated industry will bring about rapidly maturing trade associations to represent the interests of these companies primarily in the nation's capital and result in a much closer liaison between the federal government and private industry in the field of aquaculture.

(*xi*) If commercial aquaculture is eventually inhabited by a number of large companies with vertically integrated aquaculture operations there will be, within the US Department of Commerce or Agriculture, a sub-cabinet level agency for aquaculture.

(*xii*) The successful development of large vertically integrated companies will result in experiments with various types of production units including cages, raceways, silos, recirculating systems and others not yet conceived.

(*xiii*) Most of the vertically integrated companies of the size previously mentioned will be involved in several areas of aquaculture with perhaps one species dominating 70–80% of their total aquaculture generated income.

(*xiv*) Regulations by the Environmental Protection Agency (EPA) will enhance rather than inhibit the development of vertically integrated aquaculture industries.

(*xv*) The vertically integrated companies will successfully market the fact that their product is produced by aquaculture rather than by nature. This will have a marketing thrust that the product is, therefore, superior in quality, palatability and nutritional value.

6 Summary

Vertically integrated aquaculture will be a vital part of the future of commercial aquaculture in the United States and the developed world. If aquaculture is to become a significant source of fish and shellfish for the world consumer, numerous species will be produced on a vertically integrated basis by these companies. The companies will vary in size from very small cottage-type businesses to large multi-national companies. A discussion of vertically integrated aquaculture industry logically dwells primarily on the role of large companies since most vertically integrated industries are large. However, as commercial aquaculture becomes a strong and viable part of our food production system, a large number of comparatively smaller companies will also inhabit the industry and operate successfully. The larger companies will play a key role in the aquaculture industry of the future and will invest large amounts of money in research and development and will operate in close relationship with the federal government.

The Aquaculture Industry in Japan—Its Present and Future

A. Furukawa

Abstract
The production from aquaculture in Japan, a country with a long tradition of cultivating aquatic organisms, is steadily increasing. By 1973 the marine aquacultural yield was more than seven per cent of the total yield from marine fisheries as a whole. This increase in yield is a reflection not only of Japan's general economic development, but of increased demand for high valued products. Moreover, the Japanese have a traditional preference for sea foods in their diet. In comparison, the development of freshwater culture has been quite slow. This is partly due to preference for marine fish, but is mainly to be attributed to competition for water use with other industries.

The marine aquacultural harvest increased from about 400 000 tons (1963) to about 800 000 tons (1973) or about 44% of the total coastal fishery landings of 1·81 million tons (1973). The amount of money produced through marine aquaculture also increased from US$ 220 million (1963) to US$ 750 million (1973) or 65% of the money (US$ 1·15 thousand million) resulting from the entire coastal fishery landings (1973).

Of the marine species now cultured, seven are the most important: yellowtail (*Seriola quinqueradiata*), Kuruma shrimp (*Penaeus japonicus*), pearl oyster (*Pinctada fucata*), Japanese oyster (*Crassostrea gigas*), scallop (*Patinopecten yessoensis*) and two algae, Nori (*Porphyra*) and Wakame (*Undaria*). (Their production in 1973 is summarized in Table 1.) The total amount of money earned by culture of all seven species was US$ 717 million or about 95% of the total amount earned by the entire aquaculture industry excluding that gained by seedling production. The culture of two other species has made remarkable growth lately: in 1973 red seabream (*Pagrus major*) culture yielded 2 741 tons and the brown alga Konbu (*Laminaria*) culture yielded 7 681 tons.

Of a total estimated area of 71 430 km² potentially available for marine aquaculture in 1968 (with water from 0 to 50 m in depth) minus the areas for set nets, those restricted for harbour zones, *etc.*, and those unavailable because of polluted water or use as ship routes, only 5% were licensed for aquacultural use. Recent production trends in the culture of three representative marine organisms indicate steady growth as measured by the increase in number of Nori nets, oyster rafts and area occupied for yellowtail culture.

The major species used in Japanese freshwater culture are: trout (mainly rainbow *Salmo gairdneri*), common carp (*Cyprinus carpio*), silver carp (*Hypophthalmichthys molitrix*), eel (*Anguilla*), grey mullet (*Mugil*), loaches (family *Cobitidae*) and ayu (*Plecoglossus altivelis*). With respect to freshwater culture, annual production in 1973 reached about 64 thousand tons (2·8 times that of 1963) and earnings in 1973 were about US$ 173·6 million (5·6 times that of 1963).

Technical problems with respect to future aquaculture development in Japan which remain to be solved include the following: (*i*) A stable supply of young seedlings has to be secured and seedling techniques established. (*ii*) New systems must be devised which will not only improve the efficiency and equipment of each unit of a culture plant but will combine the use of various plants. Furthermore aquatic areas used for culture must be expanded. (*iii*) New species should be cultivated and the quality of the final products carefully controlled step by step depending upon use. (*iv*) Feeding facilities and equipment should be improved and diets of reasonable price and high efficiency formulated. Measures for prevention and treatment of diseases should be established.

It is believed that, in future, plants operated by family labour and those managed by corporate bodies will continue along parallel courses. Aquaculture will tend more and more to the intensive farm. New policies for the use of culture grounds may also be necessary.

L'industrie aquicole au Japon—situation actuelle et perspectives d'avenir

Résumé
Au Japon, pays qui jouit d'une longue tradition de culture des organismes aquatiques (tant animaux que végétaux), la production de l'aquaculture augmente régulièrement, en eau douce comme en eau de mer.

En 1973, le rendement de l'aquaculture marine a excédé de plus de 7 pour cent celui des pêches maritimes dans leur ensemble. Non seulement cet accroissement du rendement reflète le développement économique général du Japon, mais il correspond aussi à une demande accrue de produits de haute valeur. En outre, les Japonais manifestent traditionnellement une préférence pour les produits de la mer dans leur régime alimentaire.

Par comparaison, le développement de l'aquaculture en eau douce a été relativement lent. Cette différence s'explique en partie par la préférence des Japonais pour le poisson de mer, mais elle est surtout imputable à la concurrence des autres industries en ce qui concerne les usages de l'eau.

La récolte de l'aquaculture marine a augmenté, passant de quelque 400 000 tonnes (1963) à environ 800 000 tonnes (1973), soit quelque 44 pour cent du total des débarquements de la pêcherie côtière, qui ont atteint 1,81 millions de tonnes en 1973. Le rendement financier de l'aquaculture marine s'est également accru de US$220 millions (1963), il est passé à US$750 millions (1973), soit 65 pour cent des recettes (US$1,15 milliard) imputables au total des débarquements de la pêcherie côtière (1973).

Parmi les espèces marines actuellement cultivées, 7 sont particulièrement importantes: la sériole (*Seriola quinqueradiata*), la crevette Kuruma (*Penaeus japonicus*), l'huître perlière (*Pinctada fucata*), l'huître japonaise (*Crassostrea gigas*), la coquille Saint Jacques (*Patinopecten yessoensis*), et deux algues, Nori (*Porphyra*) et Wakame (*Undaria*). (On trouvera le résumé de la production pour 1973 au Tableau 1.) Le montant total des recettes pour les 7 espèces a atteint US$717 millions, soit quelque 95 pour cent du montant total des gains de l'industrie aquicole, à l'exclusion de ceux fournis par la production d'alevins sélectionnés. Ces temps derniers, la culture de deux autres espèces a fait des progrès remarquables en 1973, l'élevage du sparide (*Pagrus major*) a donné 2 741 tonnes de produit, et la culture de l'algue brune konbu (*Laminaria*) a donné un rendement de 7 681 tonnes.

Sur une superficie totale disponible pour l'aquaculture marine estimée en 1968 à 71 430 km² (fonds de 0 à 50 m) dont il faut retrancher les zones réservées aux filets fixes, les zones portuaires, etc., ainsi que les aires inutilisables parce que polluées ou parcourues par les navires, les demandes de permis d'exploitation pour l'aquaculture n'ont porté que sur 5 pour cent des surfaces. Les trois organismes marins représentatifs indiquent une croissance régulière mesurée par l'augmentation du nombre des filets à porphyras, des radeaux à huitres et des aires consacrées à l'élevage de la sériole.

Les principales espèces utilisées par l'élevage japonais en eau douce sont les suivantes: truite (essentiellement truite arc-en ciel, *Salmo gairdneri*), carpe commune (*Cyprinus carpio*), carpe argentée (*Hypophthalmichthys molitrix*), anguille (*Anguilla*), mulet (*Mugil*), loche (famille Cobitidae) et ayu (*Plecoglossus altivelis*). En 1973, la production annuelle de la pisciculture en eau douce a atteint quelque 64 000 tonnes (2,8 fois le chiffre de 1963), et les recettes ont été d'environ US$173,6 millions (5,6 fois celles de 1963).

Parmi les problèmes techniques qui restent à résoudre touchant le développement futur de l'aquaculture au Japon, on cite les suivants: (*i*) Il faut assurer un approvisionnement stable en jeunes alevins sélectionnés et mettre au point des techniques d'alevinage. (*ii*) On doit concevoir des systèmes nouveaux qui non seulement amélioreront l'efficacité et l'équipement de chaque unité au sein d'une exploitation aquicole, mais permettront l'utilisation combinée de diverses exploitations. En outre, il importe d'étendre les superficies aquatiques servant à l'aquaculture. (*iii*) L'on devra cultiver de nouvelles espèces et contrôler soigneusement la qualité des produits finis, étape par étape, en fonction de leur utilisation. (*iv*) Il convient d'améliorer les procédés et l'équipement servant à l'alimentation et de formuler des régimes alimentaires de haute efficacité et à un prix raisonnable. L'on devra également établir des procédures de prévention et de traitement des maladies.

L'on pense qu'à l'avenir les exploitations familiales et celles qui sont gérées par des sociétés se développeront parallèlement. L'aquaculture tendra de plus en plus à devenir une exploitation intensive. Il pourra alors être nécessaire de mettre au point de nouvelles politiques touchant l'utilisation des espaces de culture.

Presente y futuro de la industria acuícola en el Japón

Extracto
La producción de la acuicultura en aguas marinas y dulces en el Japón, país con una larga tradición de cultivo de organismos acuáticos (tanto animales como vegetales), aumenta continuamente.

En 1973 la producción de la acuicultura en aguas marinas representaba más del 7 por ciento de la producción total de las pesquerías marinas. Este aumento del rendimiento se debe no sólo al desarrollo económico general del Japón sino también a la creciente demanda de productos de alto valor. Además, los japoneses sienten tradicionalmente preferencia por los alimentos de origen marino. El desarrollo de la acuicultura en aguas dulces ha sido, en comparación, bastante lento, debido en parte a la preferencia por los peces marinos, pero sobre todo a la competencia por el uso del agua con otras industrias.

La producción de la acuicultura en aguas marinas aumentó de unas 400 000 toneladas (1963) a cerca de 800 000 (1973), lo que representa cerca del 44 por ciento de la pesca costera total, que alcanzó 1,81 millones de toneladas (1973). También aumentó el valor de la producción de la acuicultura en aguas marinas, pasando de US$220 millones (1963) a US$750 millones (1973), que representan el 65 por ciento del valor del pescado descargado por las pesquerías costeras en 1973 (US$1 150 millones).

Entre las especies marinas que actualmente se cultivan, son siete las de mayor importancia, pez limón (*Seriola quinqueradiata*), camarón

'kuruma' (*Penaeus japonicus*), ostra perlífera (*Pinctada fucata*), ostra japonesa (*Crassostrea gigas*), vieira (*Patinopecten yessoensis*) y dos algas, Nori (*Porphyra*) y 'Wakame' (*Undaria*). (Su producción en 1973 se resume en el Cuadro I). Los ingresos totales derivados del cultivo de las siete especies ascendieron a US$ 717 millones, o sea cerca del 95 por ciento de los ingresos totales de la industria acuícola, excluyendo los derivados de la producción de semilla. En los últimos tiempos ha aumentado notablemente el cultivo de otras dos especies, en 1973, el cultivo de mero (*Pagrus major*) produjo 2 741 toneladas y el cultivo de un alga marrón, 'konbu' (*Laminaria*), produjo 7 681 toneladas.

De una superficie total estimada en el 1968 de 71 430 km² adecuados para la acuicultura en aguas marinas (con aguas de 0 a 50 m de profundidad), menos las superficies reservadas para calamento de redes fijas y zonas portuarias, etc., y las inutilizables por estar las aguas contaminadas o por servir de rutas marítimas, sólo se concedieron licencias para utilizar un 5 por ciento del total para fines acuícolas. La reciente trayectoria de la producción mediante cultivo de tres organismos marinos representativos muestra un continuo aumento, como indica el incremento del número de redes para Nori, de balsas para ostras y de la zona ocupada para el cultivo de pez limón.

Las principales especies utilizadas en el Japón para la piscicultura en aguas dulces son: trucha (principalmente trucha arco iris *Salmo gairdneri*), carpa común (*Cyprinus carpio*), carpa plateada (*Hypophthalmichthys molitrix*), anguila (*Anguilla*), mugil (*Mugil*), locha (familia Cobitidae) y ayu (*Plecoglossus altivelis*). La producción anual llegó en 1973 a unas 64 000 toneladas (2.8 veces más que en 1963) y los ingresos fueron en el mismo año de unos US$ 173.6 millones (5.6 veces más que en 1963).

Entre los problemas técnicos para el desarrollo de la acuicultura en el Japón que quedan aun por resolver figuran los siguientes: (*i*) Ha de asegurarse un suministro estable de formas juveniles para semilla y determinar las técnicas de siembra. (*ii*) Han de prepararse nuevos sistemas que permitan mejorar la eficiencia y el equipo de cada unidad de las instalaciones de cultivo y permitan combinar entre sí varias instalaciones. Es necesario además ampliar la superficie acuática utilizada para cultivo. (*iii*) Es preciso cultivar nuevas especies y controlar cuidadosamente la calidad de los productos finales, fase por fase, según los fines a que se destinen. (*iv*) Hay que mejorar las instalaciones y el equipo para la alimentación de los peces y preparar raciones alimenticias de precio razonable y elevada eficiencia. Han de establecerse medidas para prevenir y tratar las enfermedades.

Se cree que, en el futuro, las instalaciones administradas por grupos familiares y las explotadas por corporaciones seguirán progresando paralelamente. La acuicultura tenderá cada vez más al empleo de técnicas intensivas. Tal vez sea necesario también preparar nuevas políticas para el aprovechamiento de las zonas de cultivo.

1 Introduction

'Aquaculture', a major book on the subject, with the subtitle, 'The farming and husbandry of freshwater and marine organisms' states that, 'In a general way, aquaculture practices may be characterized by the relative intensity of human effort applied to them' (Bardach, Ryther and McLarney, 1972).

Japan has the longest history of aquaculture in the world and from their extensive experience in this field many Japanese workers have defined aquaculture from various points of view. The Resources Council, Science and Technology Agency, provided a rather conclusive definition in its report (1974): '. . . aquaculture is an industrial process of raising aquatic organisms up to the final commercial product within properly partitioned aquatic areas, controlling the environmental factors and administrating the life history of the organisms positively, and it has to be considered as an independent industry from the fisheries hitherto'.

In using public waters to produce biological products, there are concepts and practices similar to those employed in aquaculture. The first, *Zohshoku* (propagation) is a way to facilitate the reproduction and growth of aquatic organisms, based on the productive potential of water bodies, while controlling the environmental elements and the life history of the organisms directly or indirectly; it is a practical technique to maintain and enhance fishery production. Similarly, coastal fisheries should aim basically at a production process whereby there is a harvest of the crop most suitable for maintaining a good population level of biological resources, meanwhile nurturing them actively. This ideal production process is termed *Saibai Gyogyoh* (fish farming). Under any concept of these production processes, there are several practical techniques which are basically the same.

This paper describes and analyses the trends of the major aquaculture industries of Japan, and presents perspective on them in accordance with the concept of aquaculture as defined by the Resources Council. Individual practical techniques are not detailed.

2 Production trends in aquaculture

2.1 *Long-term trends*

The marine and freshwater aquacultural production of Japan during the last sixty years is plotted in Fig. 1. Production in both types of water increased steadily except during the period of the second world war and the years immediately following. Maricultural production has increased remarkably since 1950, coinciding with the economic development of Japan after the war. This increase can be attributed primarily to the culture of four organisms: a red alga called 'Nori' (*Porphyra*), a fish, the 'Hamachi' or yellowtail, a shellfish, 'Kaki' or oyster, and another alga, 'Wakame' (*Undaria*). The first two were the major contributors. The annual marine aquacultural yield occupied merely a small portion of the total marine fishery yield for a long period of time. This occupancy has increased step by step, however, and in 1973 it was more than 7% of the total marine yield.

The organisms which are profitable in aquaculture are those which bring a high price in the market; and an increase in their production, *viz.*, an increase in demand for them, reflects the general economic development of a country. This is strongly emphasized in Japan, a nation which has a traditional preference for sea foods in its diet.

The development of freshwater aquaculture in Japan has been quite slow compared with that of marine culture (Fig 1). This is attributed to the competition in water use with other industries which have developed rapidly since the war and which consume the greater part of available water. Such competition necessarily suppressed the development of freshwater aquaculture. The use of water for irrigation is also responsible for the very slow recovery of freshwater culture. Not only was water removed for irrigation, but the presence of agricultural insecticides in irrigation and drainage water completely eliminated its re use for aquaculture. The slow growth of freshwater aquaculture may also be partially caused by the Japanese preference for marine rather than freshwater fish.

Aquacultural production in Japan has been expanding in line with the nation's economic development, *ie*, parallel to the growth of consumer economy after the second world war. It has not always followed the national policies for food producing industries, but has functioned as one of the major commercial activities producing aquatic foods.

2.2 *Recent trends*

During the period of 1963–73, the Japanese economy was rapidly growing. The apparent gross national product grew from Japanese Yen 25·6 trillion (US$ 85·3 thousand million) in 1963 to Japanese Yen 115·3 trillion (US$ 384

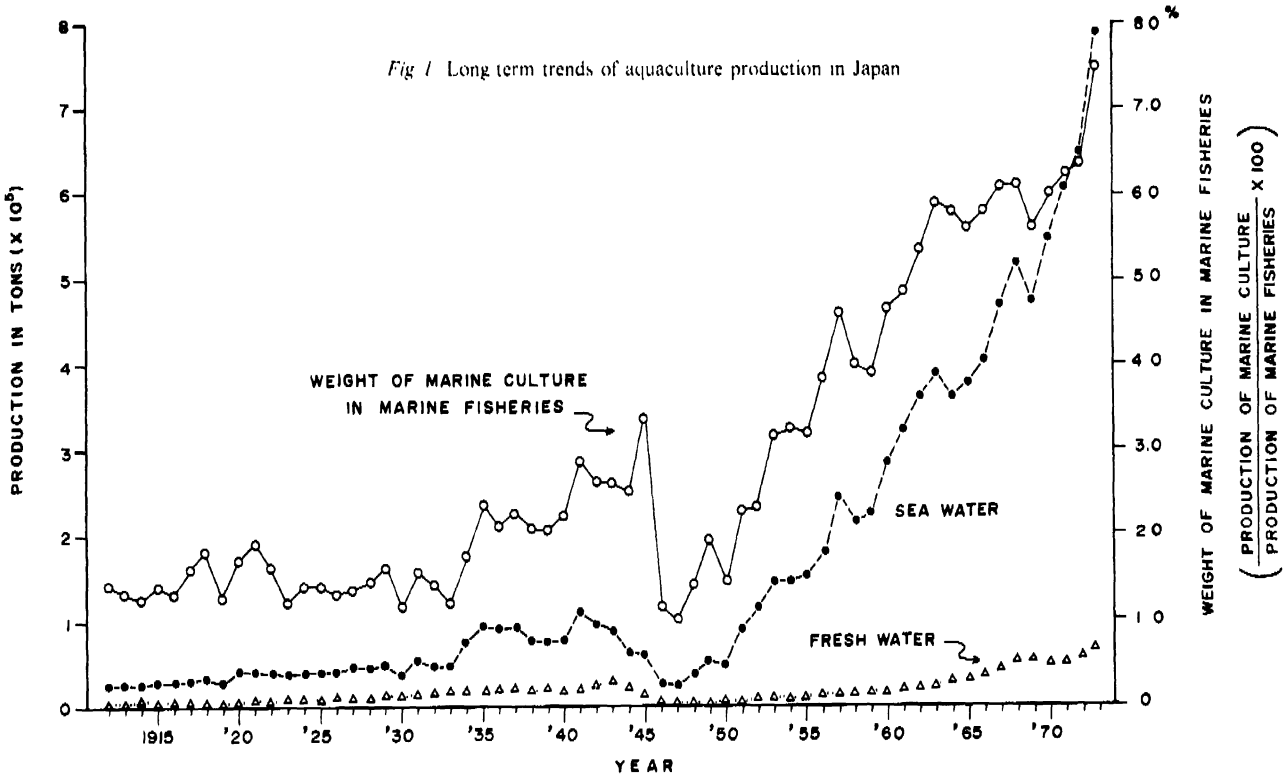


Fig 1 Long term trends of aquaculture production in Japan

thousand million) in 1973. Elevation of the national income modified the life style of the people not only in urban but also in rural areas: their selectivity of consumer goods has been diversified and directed to a demand for higher grades of goods. This has also happened with respect to their demand for sea foods during the decade.

As aquatic production is essentially governed by the available amount of standing stock, the supply of specified high valued fish, shellfish, and seaweed does not always satisfy the demand. To meet increasing demand, a new source of supply has to be found. Aquaculture is playing this role: it is the new source which supplies the high-valued sea foods.

2.2.1 *Marine aquaculture.* The changes in marine aquaculture during the period of 1963–73 are shown in Fig 2.

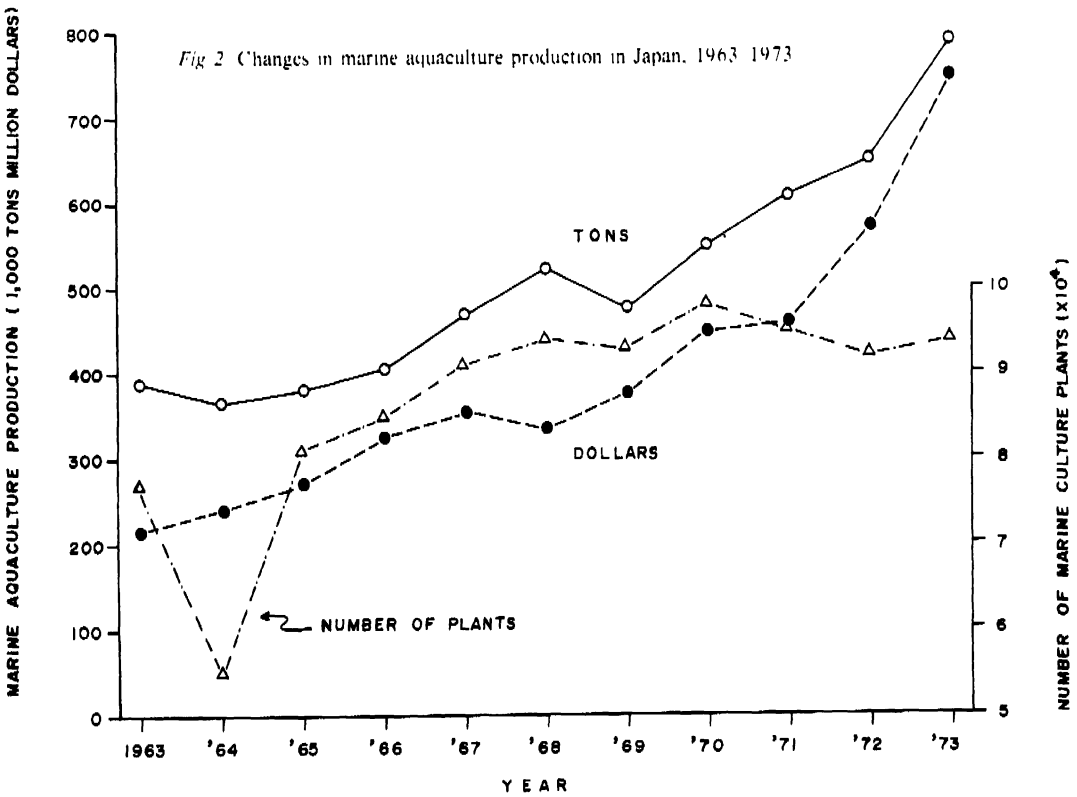


Fig 2 Changes in marine aquaculture production in Japan, 1963–1973

The total number of aquaculture plants in this field decreased sharply in 1964, and then gradually increased; growth has been stagnant in recent years. The decline in 1964 is mainly to be attributed to the decrease in the number of Nori (*Porphyra*) culturists who were obliged to leave their algal farms because of industrial invasion of coastal areas.

The amount of harvest increased year by year; it grew approximately twofold during these 10 years, reaching about 800 000 tons in 1973. This was about 44% of the total coastal fishery landings of 1·81 million tons in the same year.

The amount of money earned through marine aquaculture during this decade also increased: it more than tripled in 10 years, from US$ 220 million (1963) to US$ 750 million (1973). Growth within the last few years has been remarkable. The annual production of the coastal fisheries in 1973 amounted to Japanese Yen 344·6 thousand million (US$ 1·15 thousand million); marine aquaculture produced an amount corresponding to 65% of this.

Fifteen marine species which are now being cultured are recorded individually in fishery statistics, the others are lumped together. The following seven species are the most important: yellowtail (*Seriola quinqueradiata*), Kuruma shrimp (*Penaeus japonicus*), pearl oyster (*Pinctada fucata*), Japanese oyster (*Crassostrea gigas*), scallop (*Patinopecten yessoensis*), Nori (*Porphyra spp.*), and Wakame (*Undaria*), a brown alga. Their production in 1973 is summarized in Table I.

TABLE I
ANNUAL PRODUCTION FROM MAJOR JAPANESE MARINE AQUACULTURES, 1973

Species	*Production (tons)*	*Earnings (US$ million)*	*Number of plants*	*Earnings per plant (US$)*
Yellowtail	80 439	151	3 246	46 500
Kuruma shrimp	657	9	83	116 470
Pearl oyster*	34	54	2 526	21 500
Japanese oyster	229 899	45	5 355	8 330
Scallop	39 297	24	8 090	3 000
Nori	311 400	397	47 733	8 300
Wakame	113 211	37	20 804	1 770

*Not cultivated for food

The total yield in 1973 of these products (excluding that from pearl oysters—which are cultured for pearls, not food) was 774 903 tons. The total amount of money earned by culture of these species was US$ 717 million; this is about 95% of the total amount earned by the entire aquaculture industry, excluding that gained by production of seedlings. Even if the earnings from seedlings were included in the total (from all aquaculture), these seven products contributed 93% of the entire earnings (US$ 771 million) of Japanese marine aquaculture.

The growth of red seabream (*Pagrus major*) and the brown alga, Konbu (*Laminaria*) cultures has also been quite remarkable in recent years. In 1973, they yielded 2 741 and 7 681 tons respectively.

Nori culture, which has the greatest yield in both weight and money among the marine organisms now cultured in Japan, showed a characteristic variation throughout the decade. The yield remained around 100 000 tons up to 1970, and then jumped to a level of 200–300 000 tons. Increasing demand for this product, with the rapidly growing economy of Japan, is responsible for this development. On the other hand, there has been a progressive internal change in Nori culture during the past 10 years. The availability of processed Nori seems to have stimulated consumer demand, and the traditional final product of *Porphyra*, paper-like Nori, has been steadily replaced with processed Nori. Such a change in consumer preference also seems to have induced rapid growth in Nori production. A large amount of paper-like Nori has been used as the material for processed Nori; and the many Nori culturists have become the material suppliers to the food industry. It is estimated that the processed Nori now constitutes more than 70% of all the final products. In general, when an aquacultural product saturates demand at a market, the Japanese economy requires that the culturists locate another market where a new way of utilizing the product can be expected, and the final product be converted into a material for the food industry as in the case of Nori.

It is difficult to present the entire picture of the areas used for marine aquaculture in Japan, but one may be able to gain an understanding of its extent from Table II which gives estimates of the licensed and available areas for marine aquaculture in 1968. The technical limitations in aquacultural utilization of marine areas are also indicated in Table II which shows that areas shallower than 20 m are much more used in comparison with those areas 20–50 m in depth.

Recent production trends in the culture of three representative marine organisms (*Porphyra*, oyster and yellowtail) are shown in Fig 3, using the number of *Porphyra* nets, oyster rafts, and the area occupied by yellowtail culture as indices. These have all been increasing steadily.

TABLE II
ESTIMATED AREAS (km²) LICENSED AND AVAILABLE FOR MARINE AQUACULTURE IN 1968

	Water depth (m)		*Sum*
	0–20	20–50	
(1) TOTAL AREA	29 248	42 182	71 430
(2) Licensed area	2 541	560	3 101
(3) Set net area	637	309	946
(4) Restricted area*	3 782	747	4 529
(5) Unavailable area†	2 347	1 265	3 612
(6) 1–(3+4+5)	22 482	39 861	62 343
(2/6)×100(%)	11·3	1·4	5·0

*Harbour zone, etc.
† Polluted area, ship route, *etc.*

2.2.2 *Freshwater aquaculture.* The major species used in Japanese freshwater culture are: trout (mainly rainbow, *Salmo gairdneri*), common carp (*Cyprinus carpio*), silver carp (*Hypophthalmichthys molitrix*), eel (*Anguilla*), grey mullet (*Mugil*), loaches (family Cobitidae) and ayu (*Plecoglossus altivelis*).

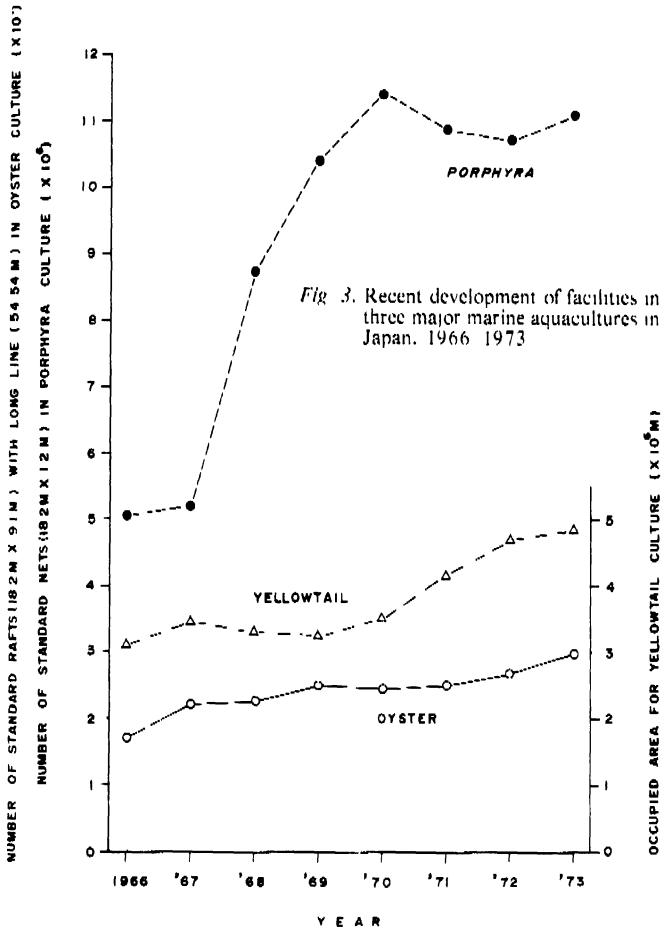


Fig 3. Recent development of facilities in three major marine aquacultures in Japan. 1966–1973

Fig 4 shows the changes in their annual production and earnings during the period 1963–73. Both have increased steadily during the decade: production in 1973 reached about 64 000 tons (Table III), 2·8 times that of 1963, and the amount of money earned in 1973 through their culture was 5·6 times that earned in 1963.

The production of freshwater culture is much smaller than that of marine culture, *eg*, in 1973 the entire freshwater production (64 000 tons) was less than that of the single marine species, yellowtail (80 000 tons). However, the products of freshwater culture are of great variety, and help meet the diversified food demands of the Japanese.

3 Problems to be solved for future aquaculture development

It is expected that both saltwater and freshwater aquaculture will continue to develop in Japan, but many problems must be solved to ensure a steady development in future. Some of these problems will be discussed below.

3.1 *Technical problems*

3.1.1 *Seedlings.* A stable supply of young seedlings has to be procured to stabilize aquaculture as an independent industry. Seedling production techniques for this purpose must be promptly established.

This applies not only to the species which are now cultured but also to those to be cultured in future, and systems of seeding must go hand in hand with mass production of young.

3.1.2 *Improvement of facilities and expansion of aquaculture areas.* To date, attention has been concentrated on improving the efficiency of each unit of a culture plant, but it is necessary to create new systems which will combine the use of various plants for more efficient production and improve their facilities and equipment. It is also necessary to expand the aquatic areas used for aquacultural production.

3.1.3 *Variety of organisms and improvement of product quality.* Efforts should be made to cultivate new species (*ie*, ones yet untried) to meet possible expansion of future demands for sea foods. The quality of the products has to be carefully controlled to suit the requirements for consumption or processing.

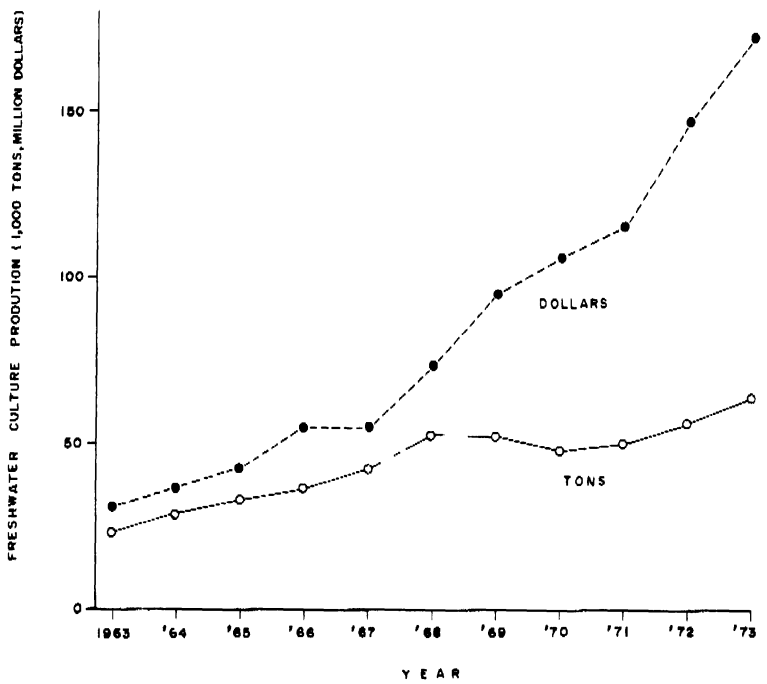


Fig 4. Changes in freshwater aquaculture production in Japan, 1963–1973.

TABLE III
ANNUAL PRODUCTION FROM MAJOR JAPANESE FRESHWATER AQUACULTURES, 1973

Species	*Number of plants*	*Area (1 000 m²)*	*Production (ton)*	*Earnings (US$ million)*
Trout	2 078	2 108	16 444	25·8
Common carp	6 709	44 640	26 344	37 6
Silver carp	421	25 323	1 227	0 8
Eel	3 250	28 365	15 037	88·1
Grey mullet	16	1 449	201	
Loach	254	188	168	
Turtle	81	300	45	21·3
Ayu	492	537	4 419	
Others	177	573	133	
Totals	13 478	103 483	64 018	173·6

3.1.4 *Nutrition and disease.* It is very important to improve the feeding facilities and equipment, and formulate diets of reasonable price and high efficiency for each species.

Although prevention of diseases is paramount, therapeutic methods for each disease of cultured organisms should also be established quickly.

3.2 *Future management*

Plants operated by family labour and those managed by corporate bodies of various classes will continue along parallel courses for some time. Aquaculture will tend more and more toward an intensive form in future, and management will have to keep pace with this technical development. Finally, as multiple-use of the environment increases, new policies may also be necessary with respect to the use of culture areas.

4 References

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Aquaculture in the Southern United States

O. W. Dillon, Jr

Abstract

Aquaculture has become an important use of land and water resources in the southern United States. Aquaculture as practised here, is on private land and is financed by private enterprise for a profit.

The cultivation of the principal fish crops is discussed with emphasis on that of: channel catfish (*Ictalurus punctatus*), trout (mainly rainbow, *Salmo gairdneri*), bait minnows (*Notemigonus crysoleucas, Pimephales promelas, Carassius auratus*), largemouth buffalo (*Ictiobus cyprinellus*) and crayfish (*Procambarus*). Polyculture, including that of *Tilapia*, is discussed.

Service by the US Department of Agriculture Soil Conservation Service to landowners and operators includes such assistance as resource analyses, soils surveys, engineering design, and management of fish farms. Such a system incorporates research and experience information in such a way that each new enterprise benefits from previous experience.

Aquaculture dans le sud des Etats-Unis

Résumé

L'aquaculture est devenue une importante utilisation des ressources en terres et en eaux dans le sud des Etats-Unis. L'aquaculture, telle qu'elle est pratiquée dans cette région, se fait sur des terres privées et est financée par le secteur privé en vue d'en retirer un profit.

L'élevage des principales espèces de poisson est examinée et plus particulièrement: *Ictalurus punctatus, Salmo gairdneri, Notemigonus crysoleucas, Pimephales promelas, Carassius auratus, Ictiobus cyprinellus*, et *Procambarus*. La polyculture, y compris celle de *Tilapia* est également examinée.

Le Service de la conservation des sols du Département de l'agriculture des Etats-Unis offre aux propriétaires fonciers et aux pisciculteurs une assistance dans des domaines tels que l'analyse des ressources, l'étude des sols, génie civil et la gestion des exploitations piscicoles. Le système fournit également des informations sur la recherche et l'expérience acquise de telle manière que chaque nouvelle exploitation bénéficie de l'expérience accumulée.

La acuicultura en el sur de los Estados Unidos

Extracto

La acuicultura ha pasado a ser una forma importante de aprovechamiento de las tierras y las aguas en el sur de los Estados Unidos, donde se practica en terrenos privados y con inversiones de empresas privadas.

Se examina el cultivo de las principales especies, prestando especial atención a las siguientes: bagre de canal (*Ictalurus punctatus*), trucha (principalmente arco iris, *Salmo gairdneri*), ciprínidos (*Notemigonus crysoleucas, Pimephales promelas, Carassius auratus*), *Ictiobus cyprinellus*, y cangrejo (*Procambarus*). Se estudió también el policultivo, incluido el de *Tilapia*.

El Servicio de Conservación de Suelos del Departamento de Agricultura de los Estados Unidos dispone de un servicio de información para los propietarios y piscicultores, que facilita asistencia en lo relativo a análisis de recursos, reconocimientos de suelos, diseño industrial y explotación de granjas piscícolas. El sistema recoge además información sobre investigaciones y experiencias, de manera que toda nueva empresa puede aprovechar la experiencia conseguida anteriormente.

1 Introduction

Aquaculture, or fish husbandry, is an important use of land and water resources in the southern United States, including the states of Alabama, Arkansas, Florida, Georgia, Louisiana, Mississippi, North Carolina, Oklahoma, South Carolina, Tennessee and Texas. Fish husbandry here produces a sizeable income to southern landowners and operators. It is practised on private land and financed by private enterprise for profit. Products go to live haulers to be sold in distant market areas: in pay lakes, as on-farm sales, or in commercial food markets. Fish produced with public monies at state, federal, or university fish-producing facilities in the southern United States are mostly for stocking public sport fishing waters or for research. Bait minnows, channel catfish, crayfish (crawfish) and trout are the principal crops, although largemouth buffalo, carp (*Cyprinus carpio*), black bass (*Micropterus*), sunfish (various species of Centrarchidae) and others are also grown. There are also a number of tropical or ornamental fish producers, but this type of fish culture is very specialized and not usually attempted as part of an agricultural enterprise.

2 Channel catfish

Channel catfish, a popular food fish, are produced in the U.S.A. mostly by southern fish farmers. Some are grown in the same ponds year after year and some are grown as part of a rice/fish or soybean/fish crop rotation.

Growth of the channel catfish industry has been phenomenal. This catfish, although normally a stream dweller, has readily adapted to still water culture. Prior to 1959, success in growing channel catfish in ponds was limited. What had kept the industry from developing up to this time was the lack of a dependable spawning method that would produce the millions of fingerlings needed for stocking each year.

Clemens and Sneed's (1957) work was the first successful attempt at spawning large numbers of this species. As spawning methods were improved, several farmers, using the method of reproduction developed by Sneed and Clemens (1959), began to produce large numbers of fingerlings to stock their ponds. The year 1960 was a year of moderate expansion, yet the acreages were still small compared to 1975.

Fish farmers further simplified Clemens and Sneed's methods for their own fingerling production. Having crops and other livestock to care for, they did not have time to tend brood fish in pens or operate a fish hatchery. Farmers found that if they put 20–22 spawning containers in a 1 acre (0.405 ha) pond and put an equal number of pairs of catfish in the pond in the spring, the fish would spawn. The brood fish and fingerlings could be left in the pond until autumn when weather conditions and water temperatures were more favourable for handling fish. Such a method would yield more than 100 000 fingerlings/acre (247 000/ha) of brood ponds and is a method still used by many fish farmers.

Pond spawning does not produce the large number of fingerlings necessary to support a farmer who produces only fingerlings. But the advantage of pond spawning to a farmer is that he can: (*i*) produce the number of fingerlings he needs cheaply; (*ii*) produce fingerlings with a minimum of labour; and (*iii*) readily sell any surplus fingerlings.

During the development years of catfish farming, few records were kept of the number of producers or area of water used. Meyer (1968) estimated that approximately 24 000 acres (9 720 ha) were producing table-size fish and another 1 600 acres (648 ha) were producing fingerlings. Dillon (1969) reported a moderate increase to approximately 30 000 acres (12 150 ha) in food fish and 3 000 acres (1 215 ha) in fingerling production. The U.S. Department of the Interior (1970) estimated that 39 300 acres (15 917 ha) were producing catfish, another moderate increase. In the spring of 1974, the Soil Conservation Service made a survey of fish farming and found that 2 372 fish farmers were producing channel catfish on 59 128 acres (23 947 ha). The year of 1974 was the peak year. The 1975 survey showed that the number of producers was down to 1 934 and the area down to 46 441 acres (18 809 ha).

As with many other types of animal husbandry, recent economic factors have caused a decline in the area of water devoted to producing channel catfish. Late in 1973, feed costs rose rapidly as the world demand for soybeans and fish meal increased. Prices received for fish did not increase as rapidly as feed costs. The price squeeze soon eliminated the marginal or inefficient producer. Efficient producers are still growing fish. Increased costs of production, such as labour, feed, equipment and water-pumping, resulted in a net loss of 12 687 acres (5 138 ha) used for catfish production in 1975. The weight of fish produced has not decreased in direct proportion to the loss of acreage. Experience and research have helped the fish farmer to produce more weight of fish/acre. In 1969, the average farmers were producing about 1 200 lb of fish/acre (1 344 kg/ha). Five years later, production of 1 800–2 000 lb (2 017 2 240 kg/ha) of fish/acre was common.

The catfish aquaculturist is striving for better production methods. Such interest on the part of the fish farmer has stimulated research agencies, universities and individuals to probe new fields. Research is underway in many areas: superior strains of fish; polyculture; more efficient feed; improved water quality; pollution control; better feeding, harvesting and aeration equipment; and others. As results are published by researchers, fish farmers take and use new methods. It seems certain that freshwater aquaculture has a definite place among the uses of land and water resources in the southern United States and is an efficient way of producing much needed animal protein.

3 Trout

Trout have been produced in the United States for well over 100 years, with the first efforts being primarily to stock waters for sport fishing. Such markets are still important to the trout farming industry. Other markets have developed and now are also important.

The western state of Idaho, having an abundant water supply, is the largest trout-producing state in the nation, producing 50·4 million trout as of July 1974. Sales figures for the 1974 crop are not available at this time but the 1973 crop sold 0·75 million fish for stocking sport fishing waters, 0·25 million fish were maintained as brood fish or spawners and the remaining fish were marketed as processed fish for human consumption (Klontz and King, 1975).

Although the southern United States is not normally thought of as a trout producing area, it produces from 5 to 6 million lb (2·25–2·7 million kg) of trout annually. The fish produced are mainly rainbow trout (*Salmo gairdnerii*) but some brown trout (*S. trutta*) and brook trout (*Salvelinus fontinalis*) are also produced. All but three southern states (Florida, Mississippi and Texas) produce trout. A unique combination of limestone caves and abundant rainfall produces springs which have a water temperature of about 56°F (13°C) all year round. In designing trout-raising facilities, the amount of flow in the spring is used as the basis for determining raceway length, width and the number of fish such a system could produce. Commercial operations need springs with a flow of at least 500 gal/min (1·9 m^3/min). One of the largest facilities in the South was designed at a spring with a 30 000 gal/min (114 m^3/min) flow.

Trout in the South are mostly marketed through fee fishing ponds. Catchable-size fish are stocked in small ponds and sold to fishermen by the weight of fish caught. As the southern United States becomes more urban and fewer people have access to rural fishing areas, such fishing ponds become more attractive. Fishermen who have been fishing on trout streams with little success may stop at a fee fishing pond to catch trout to take home. Many people like to fish where they can enjoy scenic surroundings, but there are many others who just want to catch fish.

Marketing of trout in the South by the fish farmer is diversified. No fish farmer in the South produces trout eggs. Most are one-man operations and are just too small to

maintain brood fish. The fish farmer in the South purchases his trout eggs from large producers in the Pacific Northwest.

The trout producer hatches the eggs, raises the trout and sells them in several ways. A few are sold as 2–3 inch (5–8 cm) fingerlings to stock sport fishing ponds. But most are raised to larger sizes and sold as catchable fish. Again, there is a choice of markets—commercial sales of 500 lb (225 kg) or more, or sales directly to a fee fishing pond. Commercial prices average U.S.$ 1/lb (U.S.$ 2·20/kg) and fee fishing prices average U.S.$ 1·50/lb (U.S.$ 3·30/kg). Fee fishing operators also sell bait, tackle, cold drinks, *etc*, and dress, ice and package fish for about U.S.$ 0·25/fish, thus bringing additional income to the pond operator. There is a limited market for dressed trout sold directly from the producer to the consumer. The total income generated by trout in the southern United States is in excess of U.S.$ 6 million annually, a welcome addition to the limited income of small farmers.

4 Bait minnows

Bait minnow culture began in the United States in the early 1900s. It ranks number two in area of water used for aquaculture in the South. Meyer (1968) estimated the 1968 production as just under 24 000 acres (9 710 ha). As with catfish, 1974 was the peak year with 48 899 acres (19 790 ha) producing bait minnows. Again, labour, feed, equipment, water pumping and other increased costs of production reduced the acreage to 40 255 acres (16 290 ha) as of March 1975.

Golden shiners (*Notemigonus crysoleucas*) are the primary fish grown, although some fathead minnows (*Pimephales promelas*), goldfish (*Carassius auratus*) and others are also grown. A good minnow farmer can produce 500 - 700 lb/acre (560–785 kg/ha). Minnows grown in the South are marketed all over the United States.

The large number of artificial and natural fishing lakes plus more leisure time and longer vacations have increased the demand for commercially produced minnows. During the 1975 season, wholesale prices for minnows averaged U.S.$ 2/lb (U.S.$ 4·40/kg) for minnows weighing 3–5 lb (1·4–2·3 kg) per 1 000 fish and U.S.$ 1/lb (U.S.$ 2·20/kg) for larger minnows sold for brood fish.

Minnow ponds and also catfish ponds are constructed to be easily filled and drained, to have good access roads on the levees and to be easily harvested.

The cost of production for minnows is less than for catfish because minnows require only about 30% of the feed that catfish require for maximum production. Being smaller and having different feeding habits, bait minnows get about 60% of their feed from the aquatic ecosystem and 30% from fish feed.

Bait minnows have afforded a flexibility to fish farming that has been good for southern aquaculture. In years when catfish feed costs rose due to inflation and the high price of fish meal, the fish farmer easily changed from catfish to minnow production. When the demand for catfish grows or feed prices adjust to permit a more favourable profit margin, the fish farmer can easily go back to raising catfish for human food.

Bait minnow farming lends itself well to polyculture. Fifty to one hundred fingerling catfish/acre (124–248/ha) can be stocked in the spring and marketable-size fish can be harvested in the autumn or winter. Bait minnow production is not affected and food-size catfish are produced. The difference in food habits of each species is the apparent reason why they can be raised together.

5 Largemouth buffalo

The largemouth buffalo (*Ictiobus cyprinellus*) is a highly regarded food fish in the South. About 1 million lb (454 metric tons) are produced each year by aquaculture. Since the fish sell at a lower price, U.S.$ 0·50–0·75/lb (U.S.$ 1·10–1·65/kg), than catfish, the fish are produced by extensive rather than intensive methods so feed costs are minimal. Yields by such methods rarely exceed 100 lb/acre (112 kg/ha). The fish are usually grown in irrigation or other water storage reservoirs, although some are produced in ponds stocked only with largemouth buffalo.

As with catfish, largemouth buffalo are excellent for polyculture and are grown with both catfish and minnows. They are stocked at 25–50 fish/acre (62–125/ha) in the spring and are harvested when other fish in the pond are harvested in the autumn or winter.

6 Tilapia

Catfish farmers and researchers have been successful in raising *Tilapia aurea* with catfish. Tilapia, which are grazers, occupy a different food niche than catfish. This combination can help improve water quality and produce a good weight of tilapia without cutting down on catfish production.

Two problems confront such a combination, however. So far, people in the southern United States will not eat tilapia since it is an exotic which is not familiar to most people.

The second or more serious problem associated with growing tilapia may be the tropical nature of this fish. Winters in the South are just cold enough that tilapia do not survive. Except in South Texas, South Florida and in thermal ponds, the brood fish must be over-wintered in hatchery houses or heated ponds and put into outdoor ponds in the late spring after water temperatures rise above 70°F (21°C).

7 Crayfish

Crayfish (*Procambarus*) are a popular food in the Louisiana French areas and the New Orleans gourmet market. Originally, crayfish were taken mostly from swamps and rivers. As a result, the size of the 'crop' of crayfish varied greatly from year to year. It was very difficult to base an industry or expand gourmet markets when production was so unpredictable.

Thomas (1963) worked out the life history of the crayfish in sufficient detail to provide the knowledge necessary to make the growing of them in rice fields a dependable farm crop. Prior to his work, the growing of crayfish in rice fields was a hit or miss proposition. With the development of a dependable farming method for crayfish, the production of them has grown by leaps and bounds. LaCaze (1970) furthered our knowledge in the management of crayfish as a farm enterprise. Commercial farms in southern Louisiana produced crayfish in 26 000 acres (10 520 ha) of water in 1974.

Yields of up to 1 000 lb/acre (1 120 kg/ha) have been

achieved. The early harvest brings close to U.S.$ 1/lb (U.S.$ 2·20/kg), while the late season harvest may go below U.S.$ 0·50/lb (U.S.$ 1·10/kg). An average yield of 500 lb/acre (560 kg/ha) at a price of U.S.$ 0·50/lb (U.S.$ 1·10/kg) would return U.S.$ 6 million annually to aquaculturists growing crayfish. Research underway concerning feeding and management of crayfish should further increase yields, making crayfish farming an even more profitable aquacultural enterprise.

8 Provision of extension service

The United States Department of Agriculture, Soil Conservation Service (SCS) has made major contributions to the development of aquaculture in the United States. With field offices in nearly all counties and parishes, the SCS is able to work directly with landowners and operators whose desires or farm resources indicate some prospect for fish husbandry. SCS field offices are staffed with one or more college-trained conservationists. In addition, they can call upon technical specialists in biology, engineering, soils, water quality, waste disposal and others when specialized assistance is needed.

Assistance to private landowners, which is provided through locally organized soil conservation districts, is primarily aimed at helping the landowners incorporate an aquacultural enterprise into their ongoing farm operation. The object is to make optimal efficient use of land, water and related resources and to expand income producing opportunities.

A relatively small number of landowners have access to research data and other information needed to establish and maintain such enterprises. This group includes large-scale, commercial fish farmers who usually have aquatic or fishery biologists in their employ. To these, the SCS provides only consultation or special resource data. The majority of landowners, however, need a full range of assistance.

Typical assistance to a landowner begins with a detailed resource inventory and appraisal of all resources on his farm: soil suitability and its limitations, quality and quantity of water available, topography, climatic factors, *etc.* Economic and social resource elements are also considered: financial support, labour availability, management needs, market outlets, *etc.*

If a satisfactory opportunity is indicated by the resource appraisal and the landowner or operator decides to go ahead with an aquaculture phase of his farm operation, the SCS conservationist assists with the development of a farm plan. Such a plan includes: design of the facilities and details for operations which may include species and numbers to be stocked, feeding, waste disposal, water quality control, care and management and possibly others.

As the landowner begins installing facilities, he is given on-site assistance to assure proper construction and adherence to standards and design specifications. He is also advised as to sources of stocking materials, feeds, equipment, *etc.* and provided with job sheets, technical bulletins and other written information related to the enterprise. Every effort is made to train him in all aspects of the operation. As he gains experience and knowledge, close supervision and on-site assistance is gradually phased out until only occasional contact is maintained and he is operating the enterprise more or less independently. By and large, such a system has been quite successful.

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Role of Aquaculture in Water-Resource Development—A Case Study of the Lower Mekong Basin Project

V. R. Pantulu

Abstract

The approach taken by the Committee for the Coordination of Investigations in the Lower Mekong Basin to optimizing benefits, especially economic benefits, from water resource developments through inclusion of aquaculture, is described. Aquaculture is being considered, for incorporation into irrigation schemes through pond culture at intensive, semi-intensive, and extensive levels; in delta development through rice cum-fish culture; through cage culture and sub-impoundment culture in irrigation canals and impoundments; in rearing new species for stocking impoundments; and in rehabilitation of species endangered by water resource development schemes. In comparing economic benefits that could be derived from aquaculture, it is estimated that net return varies from U.S.$ 1 543 to U.S.$ 232 000/ha/year for pond, cage and pen culture, compared with U.S.$ 72 to U.S.$ 567 for other agricultural crops. However, the investment and annual expenditures for aquaculture are significantly higher than for agricultural crops. Other indirect benefits that can be derived from aquaculture include increased standards of health, and additional employment opportunities.

It is suggested that the value of aquaculture in water resource development projects has not been fully appreciated or understood, and appropriate institutes and departments should ensure their representation in water-resource development planning bodies.

Rôle de l'aquaculture dans la mise en valeur des ressources hydriques—étude d'un cas d'espèce: le projet du bassin du Mekong inférieur

Résumé

Le Comité de coordination des recherches dans le bassin du Mekong inférieur a décidé d'optimiser les bénéfices, en particulier d'ordre économique, de la mise en valeur des ressources hydriques en recourant à l'aquaculture. Il envisage d'intégrer comme suit, l'aquaculture dans les programmes d'irrigation en rapport avec l'aménagement du delta, pisciculture en étang de niveau intensif, semi-intensif et extensif; rizipisciculture; pisciculture en cages, dans les canaux d'irrigation et dans les réservoirs; élevage de nouvelles espèces en vue de l'empoissonnement de réservoirs et de la défense d'espèces menacées par les programmes de développement des ressources en eaux. Une comparaison des avantages économiques qu'offre l'aquaculture montre que les recettes nettes (valeurs estimatives) varient entre U.S.$ 1 543 et 232 000/ha/an pour l'aquaculture en étangs, en cages et en enclos, contre U.S.$ 72 à 567 pour les autres spéculations agricoles. Toutefois, les investissements et les dépenses annuelles que nécessite l'aquaculture sont nettement plus élevés que dans le cas de l'agriculture. Parmi les avantages indirects de

l'aquaculture, on peut citer l'amélioration de l'état de santé et la création de nouveaux emplois.

Le rôle de l'aquaculture dans la mise en valeur des ressources hydriques n'a sans doute pas été pleinement reconnu ou compris. Les instituts et départements compétents devraient veiller à se faire représenter au sein des organes de planification du développement des ressources en eau.

Función de la acuicultura en el desarrollo de los recursos hídricos—estudio del proyecto de la Cuenca del Bajo Mekong

Extracto

Se describe el método adoptado por el Comité de Coordinación de las Investigaciones en la Cuenca del Bajo Mekong para obtener un máximo de beneficios, especialmente económicos, del desarrollo de los recursos hídricos mediante la inclusión de la acuicultura. Los aspectos para los que se tiene en cuenta la acuicultura son los siguientes: incorporación en planes de riego mediante cultivo intensivo, semi-intensivo y extensivo en estanques; aprovechamiento de las zonas del delta, mediante cultivo combinado de arroz y peces; cultivo en jaulas en canales de riego y embalses; cría de nuevas especies para repoblación de embalses; y rehabilitación de especies amenazadas por los planes de desarrollo de los recursos hídricos. Calculando los beneficios económicos que pueden obtenerse de la acuicultura, se estima que los beneficios netos de la misma oscilan entre US$ 1 543 y 232 000 por hectárea/año en el cultivo en estanques, jaulas y recintos, frente a un rendimiento de los cultivos agrícolas de US$ 72 a 567. Por otro lado, las inversiones y los gastos anuales para la acuicultura son notablemente superiores a los de los cultivos agrícolas. Entre los beneficios indirectos que pueden derivarse de la acuicultura figuran la mejora del estado de salud y mayores posibilidades de empleo.

Se sugiere que no se ha apreciado o entendido plenamente el valor de la acuicultura en los proyectos de desarrollo de los recursos hídricos y que los institutos y departamentos correspondientes deberían asegurar la representación de estos intereses en los órganos responsables de la planificación del desarrollo de los recursos hídricos.

1 Introduction

A perplexing feature of many water resource development programmes in the world is the scant attention given to one of the most important aquatic resources, namely fish. This is particularly regrettable in the case of water resource projects in developing countries, where integration of fisheries development could lead to substantial economic and nutritional benefits. An exception to this general trend is the development project in the Lower Mekong Basin (Mekong Project) which is directed by the Committee for the Coordination of Investigations in the Lower Mekong Basin (Mekong Committee) based in Bangkok, Thailand.

The purpose of this project is to develop water and related resources of the Lower Mekong Basin for hydro electric power, irrigation, navigation improvement, flood control, *etc.* The Mekong Basin area includes substantial parts of Thailand and Viet Nam, and virtually all of Kampuchea and Lao. A characteristic feature of this region is that fish and fish products are of great economic and dietary importance. Fish is second only to rice in the diet of the people and is the major source of animal protein, *ie* 40–80% of the animal protein intake (Caldwell, 1972). The annual *per caput* fish consumption ranges between 12 and 22 kg in the four countries. In addition, the fishing industry is said to account for between 2 and 8% of the gross national product. The Mekong Committee instituted a fisheries programme at an early stage in its project planning to assess the probable effects of water resource development on fisheries and to take measures that would offset or minimize adverse effects and maximize benefits. Aquaculture is an important facet of this programme.

This paper outlines the approach taken in the Mekong Project to optimize benefits derived from water resource development through aquaculture, with particular emphasis being placed on economic benefits. It is considered that important and valuable benefits can be attained through integration of aquaculture with other interests in water resources development programmes.

2 Aquaculture in irrigation service areas

A new concept of utilizing non-arable but aquaculturally suitable lands in the vicinity of dams in the Mekong Basin (Pantulu, 1972, and U.S. Bureau of Reclamation (USBR), 1972) was considered to determine whether an integrated irrigation and fish farm development project would be practical and economically justified. Land deemed unsuitable for agricultural purposes because of certain soil characteristics not inimical to aquaculture, such as salinity and high alkalinity, or land with an undulating or low lying topography which was unsuitable for irrigation, was assessed for aquaculture development. The criteria applied for selection of such lands for aquacultural purposes were: a natural ground slope of 0·3–2·0%; fertile soil, absence of toxic ions, pH values between 6·0 and 8·5; minimum seepage rate, protection against flooding; freedom from contamination by polluting substances, particularly agri cultural chemicals; access to main roads; and capability for gravity water service from an irrigation canal.

A survey (USBR, 1972) conducted in connexion with the proposed Pa Mong Dam on the Mekong River (Thailand/Lao), for example, indicated that about 106 000 ha of non-arable land suitable for aquaculture was available in the irrigation service area associated with the dam. The study revealed that irrigation canals would be more fully and profitably utilized if used to supply water to fish ponds as well. Furthermore, benefits from aquaculture would be so significant as to positively affect the benefit/cost ratio of the entire development.

To determine whether the predicted aquaculture benefits could be realized, the Mekong Committee approved the construction of one 51 ha pilot freshwater fish farm in association with an irrigation scheme in each country. Preconstruction feasibility studies and operational plans, conforming to conditions that would be encountered in irrigation service areas, have been prepared for three of these fish farms (SKR International Consultants, 1974). The pilot farms will demonstrate three types of fish culture at three production levels: intensive, semi intensive and extensive. Each production level represents a specific system of raising fish in ponds and yield is principally a function of water inflow directed through ponds for aera tion, and the quality and quantity of artificial feeds that are used. Table I shows the estimated water requirements

TABLE I
EXPECTED ANNUAL YIELDS AT DIFFERENT WATER DISCHARGES FOR THREE AQUACULTURE PRODUCTION LEVELS

Production level	*Water flow rate* ($m^3/h/ha$)	*Annual yield* (*tons/ha*)
Intensive	1 000	40
	1 300	45
	1 800	50
	2 500	55
	3 500	60
Semi-intensive	150	15
	200	17
	300	20
	400	22
	600	25
Extensive	15	5
	20	6
	27	7
	35	8
	53	10

Source: SKR International Consultants (1974)

corresponding to different levels of fish yields. Water taken from irrigation outlets will pass successively through intensive, semi-intensive and extensively farmed ponds and finally return to the irrigation network. Therefore, water used for fish ponds in this system of culture is virtually nonconsumptive, a distinct additional advantage for the overall water resource project.

The proposed fish farms will each have a total water surface area of 51 ha. Of this, 45 ha would be for production ponds and 6 ha for service ponds (*ie*, hatchery, nursery, and storage ponds). The 45 ha production area would be subdivided into three subareas to demonstrate to local fish farmers techniques which could increase their current average annual fish yields of 0·3 tons/ha, obtained through traditional methods, to 10 40 tons/ha by progressive application of increasing levels of modern technology.

Species cultured would differ from country to country and would be selected on the basis of achieving high growth rate in culture systems, suitability for artificial breeding, knowledge of feeding and breeding habits, compatibility of individual species with others in polyculture, consumer preference, high market value and ease of transportation as live fish. The species selected for different levels of production at a typical pilot farm are listed in Table II.

TABLE II
PROPOSED SPECIES COMBINATIONS FOR DIFFERENT PRODUCTION LEVELS AT A MEKONG BASIN PILOT FISH FARM

Species	*Production level*		
	Intensive (%)	*Semi intensive* (%)	*Extensive* (%)
Clarias batrachus	33	30	22
Cyprinus carpio	67	40	46
Ctenopharyngodon idella		20	22
Hypopthalmichthys molitrix		10	10

Source SKR International Consultants (1974)

Artificial feeds will also be important in increasing productivity, particularly in the proposed culture techniques to be used in pilot farms. It is intended that intensity of feeding will increase progressively from extensive through semi-intensive to intensive culture methods. Feed composed of 30% protein for intensive and semi-intensive culture ponds and 21% for extensive culture ponds would be prepared from locally available materials, such as fish meal, rice bran, broken rice, soyabean meal, peanut oil cake, and sorghum.

It is considered that the proposed pilot farms will yield impressive economic benefits. It is estimated that the Internal Rate of Return (IRR) will be 35% overall and the benefit/cost ratio calculated at a 15% discount rate is 2·8. The profit/returns ratio is 35·8% and profit/investment ratio 37·3%. Each farm, which requires an investment of US$ 588 000 over a five year period, would yield an annual net profit of US$ 214 000. Compared to pilot irrigated agriculture developments where IRRs generally range from 6 to 13%, returns from the fish culture development would be very high.

Capital costs for the pilot fish farm development, which average about US$ 11 500/ha, are high. However, this is attributed to the high value of the land acquired, the high initial cost of expatriate technical expertise, and management costs for a period of five years. Therefore, this cost structure should not be regarded as typical for aquaculture development in large tracts of non-arable lands in irrigation service areas.

Estimates of capital construction costs (USBR, 1972) to implement large fish farm developments, corrected to 1974 prices, are about US$ 3 500/ha in the Thailand/Lao region. With this amount of capital expenditure it would be possible to develop aquaculture using extensive level techniques yielding an average of six tons of fish/ha/year. As already indicated, this culture system can be relatively easily adopted by local fish farmers and the inputs and level of technology needed are relatively low. Table III shows the recurring costs for this level of production and the income that could accrue from this type of operation. Figures given in the table are based on costs and prices prevailing in 1974. In comparison, the cost of development of land for irrigated agriculture is about the same, while resultant benefits are considerably lower. Estimates of annual net benefits per hectare obtained under good management from some agricultural crops (Mekong Committee, 1975) and aquaculture are given in Table IV.

TABLE III
ESTIMATED ANNUAL COSTS AND RETURNS PER HECTARE FOR FISH FARM DEVELOPMENT AT THE EXTENSIVE LEVEL

Item	*Amount (US$)*
Expenses.	
Fish fingerlings (10 000/ha)	200
Feeds (10 tons/ha/year)	2 500
Weedicides, insecticides, disease and predator control	32
Labour:	
Unskilled	100
Technical assistance	100
Annual non-project maintenance and return costs (machinery, electricity, equipment and facilities)	188
Land tax	50
Miscellaneous expenditure	63
Interest on short term operating capital	18
Annual return to capital investment	18
Total expenses	3 269
Returns to enterprise (6 tons fish/ha/year at US$ 0·79/kg)	4 740
Adjustments for operator and family labour	72
Gross income	4 812
Net income	1 543

3 Aquaculture and delta development

'Delta development' programmes with the objective of reclaiming vast areas of delta lands for year round agricultural production (mainly rice paddies), are important elements in water resource development programmes in the Mekong Basin area. Unfortunately, in delta development as in other facets of water resource development, either the protection or promotional aspects of aquaculture usually receive little attention. This is particularly disheartening, considering that waterlogged areas in deltas are more suited and are more readily and relatively inexpensively converted into aquaculture sites than into agricultural lands. Ling (1972) cites instances in several Asian countries where, depending on inputs and culture techniques employed, annual profits ranging from US$ 500 to US$ 2 500 are realized through aquaculture in delta areas. The cost of reclaiming delta lands for aquaculture ranges between US$

TABLE IV
ESTIMATED COSTS AND BENEFITS FOR AQUACULTURAL AND AGRICULTURAL OPERATIONS IN THE MEKONG BASIN

Type of operation	*Per ha/year in US$*		
	Gross value of production	*Cash expenditure*	*Net return*
Aquaculture			
In fish farms	4 812	3 269	1 543
In cages	1 370 000	1 038 000	232 000
In pens	14 000	6 600	7 400
Agriculture			
Broadcast rice (native)	115	43	72
Transplant rice (native)	191	59	132
High yielding rice (dry)	365	165	200
High yielding rice (wet)	365	148	217
Tobacco	337	101	236
Chewing cane	734	167	567
Tomato	396	98	298
Sweet corn	306	107	119
Cucumber	308	69	239
Mung beans	118	30	88
Field corn	203	100	103
Soya beans	193	90	103
Peanut	360	106	254
Cotton	448	178	270
Jute	214	69	145
Miscellaneous vegetables	412	26	386
Fruits	350	16	334

Based on Mekong Committee (1975) and Pantulu (1972, 1979)

200 and US$ 1 500 depending on the degree of sophistication in construction and the material used, and agricultural enterprises are hardly comparable to aquaculture in profitability. There is, therefore, room for imaginative proposals to develop aquaculture as an integral part of water resources development in delta areas.

4 Cage and sub-impoundment culture in irrigation canals and impoundments

Pen culture and cage culture could play very important roles in enhancing fish production in man-made lakes and irrigation canals. These techniques could also provide a lucrative occupation to people resettled from the reservoir basins. With the object of gauging their economic potential under conditions pertaining to the region, relevant information on these practices in the Mekong Basin is summarized below:

(*i*) Sub impoundment culture. Shallow marginal areas of reservoirs up to 2 m in depth are fenced off with closely-set bamboo stakes, netting or wire-mesh screens. These enclosed areas are used to culture fish. Erection of these pens is a common practice in Kampuchea and parts of Thailand. The space between two adjacent bamboo stakes or the mesh size of netting used in the construction of pens is 1–2 cm. The soil substratum of the pen encourages production of benthic organisms. Water circulating through the fencing material helps to replace the oxygen and remove the carbon dioxide within the pen and facilitates heavy stocking with fish. High production of fish is obtained if the pens are stocked with plankton and bottom-feeding fish species, and if supplementary artificial feeds are provided. In 'back-up' research for the Department of Fisheries, Thailand, Swingle (1972) reports having achieved production of 12 000 kg/ha/year in pen culture experiments conducted in Auburn, Alabama, USA using a combination of channel catfish *Ictalurus punctatus* and *Tilapia aurea* and feeding with a complete pelleted feed. Even without supplementary feeding Swingle (*op. cit.*) reports yields up to 1·4 tons/ha/year with tilapia as a result of their plankton feeding habits.

Experimental trials and reports from fish culturists in Thailand indicate that production ranging from 1·9 to 18·0 tons/ha/year was possible in pen culture, depending on the species used and the quality and quantity of feed administered. In contrast to these high yields, standing crops in reservoirs in Thailand are estimated at 5 57 kg/ha/year (Lagler, 1975) and 62·5 kg/ha/year (Swingle, 1972). Therefore, there are definite advantages to promoting large-scale pen culture in man-made lakes.

(*ii*) Floating net culture and cage culture. Culture of fish in floating cages (Pantulu, 1979) or nets suspended in water is a common practice in the countries of the Mekong Basin. Fish yields from such practices are known to be very high. In Thailand, production of 160 kg/m^2/year was obtained from cages with the catfish, *Pangasius sutchi*, even though the feeds provided were inadequate in terms of amino acid balance and vitamin content (Swingle, 1972). Other species used in Thailand in this type of fish culture are: *Cyprinus carpio, Tilapia nilotica* and *Clarias* spp. The International Center for Aquaculture at Auburn University, USA, reported obtaining yields ranging from 150 kg/m^2 with *Tilapia aurea* to 190 kg/m^2 in four months using channel catfish. In both cases complete floating pelleted feed was used. Pantulu (1979) reported that annual yields of 45–133·3 kg/m^3 of cage were obtained by fish culturists in Viet Nam using different fish species, such as barbs (*Barbus hoeveni* and *B. altus*), catfish (*Pangasius larnaudei* and *Pangasius* spp.), murrels (*Channa micropeltes* and *C. striatus*) and the common carp (*Cyprinus carpio*). Floating cage and suspended net culture of fish can be practised profitably in man-made lakes and rivers.

The practice of culturing fish in pens or cages in irrigation canals is also common in many Asian countries. Swingle (1972) cites some experiments conducted in Thailand in irrigation ditches leading to rice fields or vegetable and fruit farms. Ditches used in these experiments were approximately 1 m deep and 1–3 m wide and, depending on fertilization, supplementary feeding, the amount of water passing through the ditches and the species used, annual yields ranging from 500 to 70 000 kg/ha of water surface

area were reported. Cost/benefit figures are not available in this case, but it is presumed they would be similar to those for pen and cage culture mentioned earlier. However, one factor inhibiting development of this type of aquaculture would be pollution by insecticides and pesticides that are applied to agricultural crops in the vicinity.

5 Integrated agriculture and aquaculture

Rice cum fish culture is often cited as a promising method of producing a carbohydrate and a protein crop simultaneously in the same field, with resultant increases in economic benefits. Experimental trials in Thailand have indicated that it is possible to produce, in addition to rice, a fish crop averaging 220 kg/ha without supplementary feeding and up to 400 kg/ha with feeding (Swingle, 1972). Experimental fish culture trials conducted in irrigated paddy fields at one of the agricultural experimental and demonstration farms in the Mekong Basin yielded a fish crop of about 100 kg/ha without supplementary feeding. *Trichogaster pectoralis*, *Cyprinus carpio* and *Tilapia* sp. are species commonly used in rice-cum fish culture in the region.

Construction of homestead fish ponds, for fish culture and other purposes, is a common practice in the Mekong Basin. In a study conducted in northeast Thailand, Kloke and Patros (1975) cited instances of some farmers constructing homestead ponds for culturing fish as an integral part of an agricultural system. They concluded that, for a comparable area, farmers received 21 times more net income from supplemental fish farming than from irrigated rice farming and 74 times more net income than from non-irrigated rice farming.

While in theory there appears to be little doubt that rice cum-fish culture holds promise of yielding considerable additional economic returns and nutritional benefits to the farmer, in practice, the usefulness of its role in water resource development programmes is questionable when tied to the development of modern intensive agriculture involving the use of pesticides and insecticides. Confirmation of this statement is reflected in the fact that, despite the general knowledge of its benefits, aquaculture in irrigated rice fields is not being adopted in the Mekong Basin as might be expected. Van Heck (1974) in a sociological study of Mekong Delta fishermen, observed that rice field fish culture is 'suffering more and more from increasing application of water polluting pesticides and insecticides'. Furthermore, the initial capital outlay required coupled with the risks involved in this practice inhibit its further expansion. Farmers have to invest a part of their meagre resources to modify their rice fields if they undertake fish culture as well. Such modifications involve construction of higher dikes, as well as ditches around the periphery and sometimes in the centre of the fields to serve as sanctuaries for fish. The initial cost of stocking material (young fish) is also high. Set against this investment is the risk of losses through mortality during drought periods, predation by snakes and birds, poaching by neighbours and escape due to flooding. Added to these is the ever-present risk of mortality through contamination by agricultural chemicals.

It would, therefore, appear that rice-cum fish culture is incompatible with modern intensive agriculture, unless development of new insect-resistant strains of rice are developed rendering the use of insecticides unnecessary. On the other hand, homestead fish culture, as described by Kloke and Patros (1975), holds considerable promise for integration in agricultural systems, if effective measures are taken to insulate ponds from agricultural pollutants.

6 Introduction of new species to impoundments

Aquaculture plays an important role in the introduction of new species, where considered necessary and desirable, into man-made lakes. It is common practice in several Asian countries to construct fish farms near these water bodies with the specific objective of breeding and raising desired indigenous or exotic species of fish to a size where they can be introduced into the lakes.

Although the introduction of exotic species may not always be desirable, there is no doubt that carefully planned introductions have been highly successful (*eg*, North American trout into New Zealand, European trout into North America and parts of India, Chinese carps into India, the Indian carp (*Labeo rohita*) into Thailand, *etc*). In man-made lakes in many parts of the world introduction of indigenous or exotic species has contributed to increased fish production. For example, in Lake Ayame, Ivory Coast, it is claimed that fish production has been doubled by the introduction of *Tilapia nilotica*; also, in India, introduction of species which are new to a particular water body but are indigenous to the country has resulted in significantly increased fish production.

7 Rehabilitation of endangered species

Water resource development projects inevitably forge changes in the environment that might endanger some species of fish and other aquatic life. Where the species so endangered are commercially or biologically valuable, measures have to be taken to rehabilitate them. In the Mekong Basin, it is believed that construction of dams on the main river may endanger the survival of the following fish which are possibly migratory (Pantulu, 1973):

Cyprinidae:	Schilbeidae:
Cirrhinus microlepis	*Pangasianodon gigas*
C. jullieni	*Pangasius pangasius*
Probarbus jullieni	*P. sutchi*
Thynnichthys thinnoides	*P. sanitwongsei*

In addition to these, the survival of an important species of prawn, *Macrobrachium rosenbergii*, which undertakes seasonal spawning migrations from freshwater sections of the Mekong River to the estuaries, is likely to be threatened as a consequence of environmental changes brought about by water resource development activities.

Artificial propagation is one of the principal means employed by the Mekong Committee for rehabilitating endangered species. However, techniques for propagating all the potentially affected species are not yet known. Efforts are, therefore, being made to induce breeding and establish culture techniques for *M. rosenbergii*, *Pangasius pangasius* and *P. sutchi* in Viet Nam and *Pangasianodon gigas* in Thailand. Ultimately, the Committee intends launching large-scale programmes to produce juveniles of selected, valuable, endangered species through artificial means. It is hoped this will replace the possible loss of fry of these species from natural sources for culture purposes and also make fry available for stocking rivers or man-made lakes if required. It is expected that the culture fishery developed for some of these species would replace the losses that might occur in the natural fisheries.

8 Conclusion

A question very often asked is—how can we account for the scant attention paid to aquaculture in water resource projects, despite what appear to be its glaringly obvious advantages? The possible answers to this question are outlined below:

(*i*) Unfamiliarity with facts regarding aquaculture at decision-making levels, which seldom include fishery scientists.

(*ii*) The lack of an authority to advocate development of aquaculture and fisheries since fisheries in many governments and agencies are subordinated both administratively and technically to agriculture. With agriculturists being themselves uninformed in this field, they are hesitant to promote fisheries interests. Moreover, they generally consider it both convenient and advantageous to their pro grammes to give short shrift to fisheries considerations.

(*iii*) The lack of promotional ability among fishery scien tists is also a limiting factor. Fishery scientists, trained as they usually are in the disciplines of pure science, find it difficult to make assertive projections of benefits under assumed conditions that could be realized in the future. Also, characteristic of their training in pure science, is an ignorance or disregard of the economic aspects related to their fields. This makes it difficult for them to present their points of view convincingly to planning bodies. Fortunately, efforts are now being made to correct this deficiency and studies on economic aspects of fisheries are being encouraged.

To correct this situation, fishery scientists should disseminate knowledge of aquaculture through publication of articles in the popular press and journals devoted to economics and planning. Fishery institutes and departments in international agencies should avail themselves of every opportunity to secure representation in water resource development planning bodies. They should also try to secure an independent voice and status for units in govern ments dealing with fisheries. More emphasis should be placed on initiating actual and theoretical studies of differ ent types of aquaculture operations, especially their eco nomic aspects. Pilot projects should be established wher ever possible to demonstrate to government agencies concerned, and the private sector, the benefits that can be achieved through development of aquaculture.

If aquaculturists adopt a more forceful stance toward integration of aquaculture development with water resource development programmes, it could contribute substantially to improvement of the overall development programme. The increased production of cheap protein through aquaculture would be reflected in improved standards of health of the population covered by the project; additional employment opportunities can be provided by an aquaculture industry, ensuring lucrative means of livelihood for many people; and enhancement of economic benefits through aquaculture could be so significant as to convert an otherwise uneconomic water resource development project into an economically attractive one.

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Status and Problems of Culture of Baitfish for the Skipjack Fishery in the Pacific Region

V. Gopalakrishnan

Abstract

Production of live bait for the skipjack tuna (*Katsuwonus pelamis*) fishing industry in the Pacific forms an important component of fisheries development plans in the region. Several attempts have been made during the past years to solve the problem of shortage of live bait as well as to augment its supply to save fishing time, but the results obtained have not been encouraging. It is felt that aquaculture can contribute significantly in this direction, especially in some of the Pacific islands where there is an acute scarcity of live baitfish. A review of investigations carried out so far in the Pacific region on the culture of potential live bait species, viz. *Tilapia mossambica*, *Dorosoma petenense*, *Poecilia sphenops* and other poeciliids, *Sardinella melanura* and other clupeids, *Engraulis japonicus*, *Chanos chanos*, mullets, cyprinids and *Kuhlia sandvicensis*, highlights the problems involved in the culture and use of these species as live baitfish, and stresses the need for further studies on culture of potential live bait species.

Situation actuelle et problèmes de l'élevage de poissons-appâts pour la pêche à la bonite à ventre rayé dans la région Pacifique.

Résumé

La production d'appâts vivants pour l'industrie de la pêche à la bonite a ventre rayé (*Katsuwonus pelamis*) dans le Pacifique constitue un élément important des plans de développement halieutique de la région. Dans les années passees, diverses tentatives one été faites pour résoudre le problème du manque d'appâts vivants, ainsi que pour améliorer l'approvisionnement et économiser ainsi du temps de pêche, mais les résultats obtenus n'ont pas été encourageants. On pense que l'aquaculture pourrait contribuer notablement à l'accroissement de cette production, notamment dans certaines iles du Pacifique où la penurie est devenue aigue. Le passage en revue des recherches effectuées jusqu'a ce jour dans la région Pacifique sur l'élevage d'especes susceptibles de convenir comme appâts vivants, à savoir *Tilapia mossambica*, *Doro soma patenense*, *Poecilia vittata* et autres poeciliidés, *Sardinella melan*

ura et autres clupéidés, *Engraulis japonicus*, *Chanos chanos*, les mulets, les cyprinidés et *Kuhlia sandvicensis*, met en relief les problèmes posés par l'élevage dans cet objectif et fait ressortir la nécessité d'entreprendre des études complémentaires sur les espèces qui se prêteraient à une telle utilisation.

Situación y problemas del cultivo de peces de cebo para la pesca de listado en el Oceano Pacífico

Extracto

La producción de cebo vivo para la pesca de listado (*Katsuwonus pelamis*) en el Pacífico, constituye una parte importante de los planes de desarrollo pesquero de la región. En los últimos años se ha intentado en diversas ocasiones, solucionar el problema de la escasez de cebo vivo, así como aumentar su suministro para ahorrar tiempo de pesca, pero los resultados obtenidos no han sido alentadores. Se cree que la acuicultura puede contribuir sensiblemente en este caso, particularmente en algunas de las islas del Pacífico en las que hay una grave escasez de cebo vivo. Un examen de las investigaciones efectuadas hasta la fecha en el Pacífico sobre el cultivo de posibles especies para emplearlas como cebo vivo, por ejemplo, *Tilapia mossambica*, *Dorosoma petenense*, *Poecilia vittata* y otros poecílidos, *Sardinella melanura* y otros clupeidos, *Engraulis japonicus*, *Chanos chanos*, lisas, ciprínidos y *Kuhlia sandvicensis* realza los problemas que se plantean en el cultivo y empleo de estas especies como cebo vivo y acentúan la necesidad de efectuar otros estudios sobre el cultivo de especies que pudieran servir como cebo vivo.

1 Introduction

Tuna resources of the Central Pacific have been the subject of extensive study during the past decade. It is believed that this oceanic region may be capable of sustaining large harvests over and above the present catches, with a potential being in the order of hundreds of thousands of tons. The South Pacific Commission has recognized that the skipjack tuna (*Katsuwonus pelamis*) is probably the most important fish species involved in future development plans for the Pacific, especially in the South Pacific Islands, and that live bait pole-and line fishing is the most effective method for catching this species in the region (Baird, 1973; 1974). The estimated potential of skipjack fishing with live bait in the South Pacific is a minimum of 60 000 tons and, for the exploitation of such a fishery, a substantial quantity of live bait at attractive prices will be required (Doumenge, 1973).

Evaluation of the natural bait resources of the Pacific Ocean indicates that baitfish populations are unevenly distributed and their abundance fluctuates significantly from year to year. Although baitfish are not scarce in the Hawaii area, it has also been estimated that skipjack fishermen spend up to 50% of their time fishing for bait instead of for tuna (Shomura, 1964; Rothschild and Uchida, 1968), and mortality in bait wells can be as high as 35%.

In other areas, availability of live bait is a key factor governing exploitation of tuna stocks, even in existing fisheries. For example, the tuna fishery resources around the different islands of the Gilbert and Ellice group are reported to be appreciable and the catches of skipjack have been particularly good as long as live bait was available in the lagoons (Gopalakrishnan, 1974). Similarly, a survey conducted by the Fisheries Department during 1970–72 indicated the existence of large stocks of yellowfin (*Thunnus albacares*) and skipjack tunas but only limited stocks of live bait were available for pole-and-line fishing. American Samoa is another example where natural baitfish resources are inadequate for the potential tuna fishery (Swerdloff, 1973).

Urgent steps are therefore required to provide the necessary bait supplies for future large scale commercial tuna fishing ventures. Development of the live-bait industry is expected to be an important component of plans to expand pelagic tuna fisheries in the Pacific, in spite of the fact that techniques other than pole and line fishing are being adopted in certain areas for some species.

Several attempts have been made in the past to solve the problem of bait shortage by adopting different methods (Shomura, 1964). Of these, the feasibility of culturing baitfish has attracted considerable attention because of its relatively stable and controlled production, but previous work in this field has met with mixed success. Attempts to rear small pelagic marine fishes suitable for bait have been successful, but these were conducted under laboratory conditions and require further development before being applied in the field. Species of fish which are suitable for intensive culture in fresh waters have been tried as alternative bait, particularly in Japan, but did not perform satisfactorily under field conditions.

There is, however, continuing interest in the potential of aquaculture to meet the demand for baitfish. The feasibility of culturing suitable species, such as mollies, on a large scale in order to establish a baitfish industry is being actively considered in Hawaii (FAO, 1973) and American Samoa (Swerdloff, 1973; FAO, 1973a). An FAO/UNDP project has recently been initiated in the Gilbert and Ellice Islands to investigate the feasibility of aquaculture in lagoons, with special reference to culture of baitfish, and to undertake pilot studies in suitable areas. The holding and rearing of baitfish captured from natural waters for several weeks, by adopting elaborate management and feeding programmes, is another related activity receiving considerable attention in the region.

Support for the role of aquaculture in increasing baitfish production has been given by agencies, such as the South Pacific Commission, who have highlighted the problem of baitfish shortages and recorded that every support should be given to the culture of suitable hardy live baitfishes (Baird, 1974).

Fish culture techniques developed in recent years are considered to have application in the baitfish industry and have, in fact, been used on a small scale in some countries to meet tuna sport fishing requirements (Pillay, 1973). A tuna baitfish workshop was also organised by the U.S. National Marine Fisheries Service, in Honolulu in June 1974, to review the problems of baitfish cultivation. The importance of developing culture of baitfish in many regions was highlighted during the discussions and the need recognized for conducting feasibility studies and field trials using a variety of potential species.

This paper reviews the available information related to culture of fishes with potential use as baitfish for tunas, especially skipjack, in the Pacific region.

2 Potential baitfish species for the Pacific region

The general qualities required of cultivated baitfish are well known. The species must be prolific and have an extended breeding season, good growth rate, and must be resistant to handling, transport and diseases (Huet, 1970). Other qualities that should be considered in selecting suitable baitfish species include: survival, fishermen acceptance, availability, behaviour, size, colour, and body form. It is also important that the species selected for culture in any particular area must be adapted to the prevailing environmental conditions.

2.1 *Tilapia mossambica*—Tilapia

This is a robust fish which can withstand high water temperature as well as high salinity. The species has been introduced and cultivated in several countries in both freshwater and brackishwater ponds (Jhingran and Gopalakrishnan, 1974). The fish is an omnivorous feeder, consuming a wide variety of plants and animals. Its respiratory demand is relatively low and large numbers of juveniles can be transported easily in containers. The fish can spawn almost throughout the year in warm waters at 5–7-week intervals, with an average of 8 times per year. The reproductive potential is high, mainly due to parental care. Tilapia can spawn even in salt water, though the activity may be inhibited with increasing salinity.

Studies by King and Wilson (1975) showed that young *Tilapia mossambica* is a suitable species for use as live bait in skipjack fisheries. They found that, although the species is slightly inferior to the popular bait in Hawaii, *viz.*, nehu (*Stolephorus purpureus*), on regular overall skipjack catch results, it has compensating qualities including hardiness, adaptability to artificial conditions in bait tanks and possibility of holding for indefinite periods. With respect to size, it has been observed that tilapia of 3·8-5·0 cm length is the optimum for skipjack pole-and-line fishing (Brock and Takata, 1955; King and Wilson, 1957). Brock and Takata, however, considered that it may not be possible to culture tilapia economically on a large scale in reservoirs and ponds. In order to overcome this difficulty, further studies in Hawaii were concentrated on intensive culture of the species in concrete tanks (Hida, Harada and King, 1962). These investigations, which were conducted in 1958 and 1959, gave very encouraging results. The sea trials conducted with tilapia indicated that the fish served well as a supplementary bait to nehu. It was also reported that tilapia was a good bait for skipjack tuna weighing 8 to 11 kg. Compared with data obtained from bait-size tilapia caught from ponds near Honolulu, these authors were of the opinion that intensive culture of small tilapia in tanks is more productive and economical than by accepted pond-culture methods.

Uchida and King (1962) also conducted detailed investigations on the possibility of producing bait size tilapia in tanks constructed in Honolulu. It was observed that a combination of physico-chemical and biological factors influenced the rate of fry production and crowding, quality and quantity of food, and salinity of water affected the growth of tilapia to bait size.

A review of earlier investigations shows that small tilapia have the characteristics of a good skipjack bait and, although they may not be as good a live bait as other popular and established species, they can serve as supplementary bait and also as bait to be used from small fishing boats. Shomura (1964) found that an increase in catch may be possible by employing a dull-coloured lure when tilapia is used as the baitfish. He considered that further studies were necessary to develop tilapia as a supplementary bait, as the species has several advantages in this respect. Yuen (1969) measured the response of skipjack to nehu and tilapia, and found that the tuna responded to the former better in terms of increased catch rate, feeding attack rate and number of tuna attracted.

Considering the fact that tilapia has been introduced and become established in most of the Pacific islands and that in many islands, such as those of the Gilbert and Ellice group, the fish is not popular as a food fish, the feasibility of culturing the species for bait purposes has to be seriously considered. The fish is very hardy and tolerates a wide range of salinities, and survives well in bait containers and bait wells. The main objection appears to have come from the non-acceptability to Hawaiian fishermen of the species even as a supplementary bait, but this need not detract from the use of cultured tilapia as an auxiliary bait in other areas. A programme of extensive sea trials is now required as well as promotion of the use of tilapia as a useful baitfish.

2.2. *Dorosoma petenense*—Threadfin Shad

This fish which was introduced into rivers and reservoirs in Hawaii during 1958 and 1959, became established by 1960 (Brock, 1960; Hida and Thomson, 1962). The species has several of the qualities required for a good skipjack bait, the most important being hardiness, desirable silvery colouration, favourable breeding habits and easy acclimatization to sea water (Iversen, 1971). Hida and Thomson (1962) found that the fish spawned and established itself well in several Hawaiian reservoirs. They considered that, although cultivation of the species as live bait for skipjack fishing is difficult due to the shad's low resistance to handling, this species might be cultured in drainable tanks and ponds with facilities for acclimatization to sea water and for direct loading of stocks into bait wells of vessels. Iversen (1971) after extensive trials found that the threadfin shad occurring in Hawaiian reservoirs during the peak season of skipjack fishing are hardy, readily handled in large numbers and easily acclimatized to salt water. He found similarities in the chumming behaviour of the threadfin shad and nehu. It was estimated that sufficient quantities of this species to meet a major proportion of Hawaii's live bait requirements could be cultivated in a 120 ha reservoir.

Shang and Iversen (1971), who conducted an economic feasibility study on production of the threadfin shad as live bait, found that, with a possible production level of 740 buckets (1 700 2 400 kg) per hectare using advanced aquaculture techniques, a rearing project could be economically viable. They estimated that about thirteen 4 ha ponds would be required to produce sufficient bait to meet the requirements in Hawaii during the peak season. Harvesting the shad from an existing reservoir was also found to be profitable. The authors concluded that further investigations would be necessary in raising subsidiary crops to determine maximum levels of production, performances in actual sea trials, and construction of lower cost facilities.

2.3 *Poecilia sphenops*—Sharpnose Molly

Considerable attention has been paid in recent years to the mass culture of mollies, which are euryhaline live-bearers reaching maturity within a few weeks. The species inhabits brackishwater and seawater areas in Hawaii. The growth and fecundity of the species have been found to be influenced by population density, water temperature, salinity, rate of water exchange and frequency of feeding (FAO, 1973). The species also has many characteristics which facilitate its use as live bait (Bell and Higgins, 1939; Baldwin, 1974). Under intensive culture conditions the fish has been observed to behave well, and Baldwin (1972) found satisfactory growth and survival in 10–50% sea water. The ideal physico-chemical factors and bio-ecological parameters relating to stock density, sex ratio, food and feeding, *etc*, for the mass culture of the species have been

determined (Herrick and Baldwin, 1975). Details of brood and rearing ponds, as required in a baitfish culture industry, have also been designed. The estimates made by these authors have indicated economic viability of commercial production. They suggested further investigations on performance of the fish as live bait, behaviour in bait wells, genetic make-up, *etc*. The operations have been estimated to be of potential profit at production levels of approximately 100 tons (30 000 buckets) and 200 tons (60 000 buckets) annually.

2.4 *Poecilia mexicana*—Mexican Molly

This species, which reaches maturity in four months, has been under intensive culture in American Samoa for use as live bait (Swerdloff, 1973). It bears 30–180 fry every 28 days and the mortality of young and adults is less than 10%. The possibility of setting up production facilities is under serious consideration by the Government of American Samoa.

2.5 Other Poeciliids

The sailfin molly, *Poecilia latipinna*, has been introduced successfully into fresh and brackishwater areas of Oahu (Hawaii) and is reported to be a good live bait (June and Reintjes, 1953). This molly may also be investigated for intensive culture as skipjack bait.

The poeciliids, as a group, offer interesting possibilities as cultured live bait for the skipjack industry in many regions of the Pacific. This author has found that one species is prevalent in some freshwater tanks in Tarawa, Gilbert and Ellice Islands, and investigations on the potential for culture of this species have been initiated.

The mosquito fish, *Gambusia affinis*, has been introduced into many countries. The species is hardy, grows to about 5 cm, withstands exposure to poor water conditions, overcrowding, *etc*, and generally breeds within four months. The mosquito fish is known to be used as live bait (Bell and Higgins, 1939) and hence it is possible that mass culture of this species can be tried.

2.6 *Sardinella marquesensis*—Marquesan Sardine

Attempts to introduce this species into Hawaiian waters have apparently not been successful (Hida and Morris, 1963). These authors found indications that the fish had spawned successfully in the new environment but their failure to become available in sufficient numbers was perhaps due to their occupation of the same ecological niche as the local anchovy, nehu.

2.7 Other Clupeids

Several members of the family Clupeidae form important live bait for skipjack tuna in the Pacific region, as for example: *Harengula* spp., *Sardinella* spp., *Herklotsichthys punctatus*, *Sardinops* spp., *etc*. Although reports of actual cultivation of clupeids for the purpose of livebait supply are not available, the culture of clupeid larvae under controlled conditions appears promising. Laboratory rearing of clupeids from fertilised eggs has been successful to a certain extent (Kimura, 1970; Houde and Palko, 1970), and further investigations in this direction will be worthwhile.

2.8 *Engraulis japonicus*—Japanese Anchovy

This species is the most important baitfish used in the Japanese skipjack industry. Although culture methods are unknown, rearing the fish in bait receivers for periods extending to four months, with regular feeding programmes, has been reported from Japan. Progress has also been achieved in the hatching and rearing of larvae of the anchovy, *Engraulis mordax* (Kramer and Zweifel, 1970).

2.9 *Chanos chanos*—Milkfish

Techniques for the intensive culture of milkfish have been developed in several countries in the Indo-Pacific region. Recent reports indicate that production rates up to 4 000 kg/ha/year have been achieved in the Philippines through rearing the species in fish farm enclosures (fish pens) (FAO, 1975). Milkfish are known to have suitable characteristics for use as live bait (June and Reintjes, 1953). They are resistant to sudden changes in salinity and tolerate low oxygen content, are hardy and adapted to high temperature conditions, the rate of growth is good and they adjust well to crowding (Gopalakrishnan, 1972). Their effectiveness as live bait for skipjack pole-and-line fishing has been indicated from trials conducted in the Philippines and Line Islands (Baldwin, personal discussions). The Philippines Fisheries Commission planned to use surplus cultured milkfish as tuna bait and investigations on the culture of the species as live bait have been reported (FAO, 1970). The possibility of culturing the species for tuna bait in some Pacific islands has been receiving active consideration, and pilot investigations on the problem have been undertaken by the FAO/UNDP project in the Gilbert and Ellice Islands (Gopalakrishnan, 1975). On the basis of preliminary surveys, it has been determined that a few of the islands in the Gilbert and Ellice group have potential areas for culture of this species. The milkfish seed resources are appreciable and initial experiments on culturing the species in ponds without fertilization and feeding have given very encouraging results. Fry have been stocked in nursery ponds at the rate of 0·1 million/ha and have been observed to reach bait size in about 8 to 10 weeks. Further intensive trials are now being planned.

2.10 Mullets

Culture methods for many species of mullets are known and rapid progress is being made in culture techniques for this species in many countries of the Indo Pacific region. June and Reintjes (1953) list the following mullets as good bait for pole and-line fishery: false mullet, *Neomyxus chaptalli*; black-fin mullet, *Mugil vaigiensis*; blue-tail mullet, *Mugil longimanus*; striped mullet, *Mugil cephalus*; and thick-lip mullet, *Crenimugil crenilabis*. Sea trials using mullets as live bait have shown that their performance is good (Yuen and King, 1953; Yuen, 1969). Since these fish behave well under controlled conditions and their seed are plentiful, the possibility of culturing them for live bait purposes deserves active consideration (Gopalakrishnan, 1975). The feasibility of breeding mullets under controlled conditions has been demonstrated in several countries (Gopalakrishnan, 1972), and further intensive pilot studies on their breeding and culture in the Pacific islands are required.

2.11 Cyprinids

The silver carp, *Hypophthalmichthys molitrix*, has been introduced in several countries of the Indo-Pacific region and thrives under intensive culture conditions. Although the species is important generally as a food fish, several

investigations have been made in Japan on the use of juveniles as live baitfish (Baldwin, personal discussions). It is reported that, although the species has most of the desirable characteristics of good tuna bait, the fish's behaviour in sea trials has not been satisfactory. Similar results have been reported from Japan on the use of another commonly cultured species, the goldfish, *Carassius auratus*. Baldwin (personal discussions) has indicated that the tawes, *Puntius gonionotus*, the ugui, *Tribolodon hakonensis* and the common carp, *Cyprinus carpio*, have been tried as tuna live bait, but detailed reports are not available.

The golden shiner minnow, *Notemigonus crysoleucas*, is cultivated in fresh water over wide areas for use as bait for sport fishing. It has been estimated that about 11 000 ha in Arkansas, U.S.A. are used for farming golden shiners (J. Mayo Martin, personal communication). In North American waters, techniques adopting 'single-phase rearing' may produce 150 000 fish (bait size) per hectare and the figure is doubled with 'double-phase farming' (Huet, 1970). The species has favourable qualities as skipjack live bait and the possibility of culturing it in Hawaii is under active consideration.

2.12 *Kuhlia sandvicensis*—Mountain Bass

June and Reintjes (1953) reported that the mountain bass is excellent as live bait and can tolerate long-distance transport in bait tanks. The fish has been found to behave well in skipjack fishing trials (Brock and Takata, 1955; Yuen, 1969). However, attempts to cultivate the species as live bait did not give favourable results, mainly due to slow growth, late maturity and difficulty of breeding under controlled conditions (Tester and Takata, 1953). Since the species appears to be abundant in many islands of the Central Pacific, it is worthwhile considering further studies on its culture possibilities.

3 Conclusion

As has been pointed out by the South Pacific Commission, every possible encouragement should be given to feasibility studies on the culture of different species of fish which can serve as good live bait for the skipjack pole-and line fishing in the Pacific region. In areas, such as the Gilbert and Ellice Islands, where the entire future of the country's economy may well depend on the exploitation of marine resources, the establishment of a tuna fishing industry is conditional on the availability of adequate quantities of quality live bait. In view of the considerable distances involved and varying abundance of the natural populations of bait fish species, aquaculture can play an important role in providing bait at specific locations as demanded by the industry. With the technical advancements that are expected to take place in the field of aquaculture, many of the Pacific islands should make a determined effort to meet the challenge of producing cultured live baitfish economically.

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Insurance and Risk Management for the Aquaculture Industry

P. A. D. Secretan

Abstract

Insurance is concerned not only with buying peace of mind but with the spreading of risks and hazards and even reducing them by the control and management of pure risk, *ie*, 'risk management'. The fundamental principles of all insurance concern: insurable interest, utmost good faith, material facts, indemnity, proof of loss, proximate cause, subrogation, and contribution.

The ultimate success of an aquacultural insurance service depends not only on the efficiency and standard of its services, but on the formation and continued existence of a long-term underwriting service market for aquacultural insurance risks, particularly the risks to stock and liabilities.

Existing insurance market procedures are applicable to many aquacultural situations, but stock insurance wordings need to cater for the peculiar interests of aquacultural stock and problems also rise in the area of protecting aquacultural liabilities, particularly products liability and marine liabilities associated with offshore installations. Aquaculture is a high-risk business. Its stock is exposed to many perils, such as: pollution, disease, slaughter made necessary by disease, food poisoning, failure of water supply, breakdowns, net and cage failure, predation, flood, inclement weather, power failure, theft, negligence, storm and tempest, fire, explosion, earthquake, impact, aircraft, riot, and malicious damage. Generally, the only viable stock insurance is full 'All Risks' coverage

The main areas of aquacultural liability are: employers' liability, public liability (marine and non marine) and products liability. The first of these is a standard exposure not peculiar to aquaculturists. However, as fish farming encroaches farther into the sea, marine liability owing to collision or other damage caused by aquacultural rafts, pilings, cages, nets, *etc*, becomes a more important item requiring coverage. Products liability coverage is also important in that aquacultural activity may spread disease to other stocks of fish, its products may cause injury to man, or the equipment manufactured may cause third party injury or other damage.

Since aquacultural insurance is a new class of insurance, new policy wordings are evolving and it behoves a fish farmer to examine a proffered policy with great care especially with regard to the means for establishing the value of the aquatic animals that may be the subject of a claim. Policy holders faced with a loss should always act as though uninsured and observe the claims procedures laid down in the policy.

It is difficult to discuss costs of aquacultural insurance, but it is recommended that the buyer should use the services of an agent or broker who can search the market for the most economical and effective coverage All risks coverage is suggested and bulk buying of insurance may be economical to the fish farmer and attractive to the underwriter.

Risk management, a natural adjunct to insurance, concerns itself with: discovering the sources from which risks may arise, evaluating the impact on the individual or organization if a loss should occur, and selecting the most effective technique(s) to deal with the risk. Business risks of a technical, social or economic type, have a bearing on production, marketing and financial business risks All of these fall outside the scope of risk management. Pure, or manageable risks include physical effects of nature, technical (such as breakdowns), social deviations from standard conduct and ill effects on personnel. Insurance experience can reduce losses to fish farmers through application of risk management.

Assurance et gestion des risques dans l'industrie aquicole

Résumé

L'assurance a pour objet non seulement d'acquérir la tranquillite d'esprit, mais aussi de répartir les risques et les dangers, voire de les réduire en contrôlant et en gérant les risques purs, c'est-à-dire en pratiquant ce que l'on appelle 'la gestion des risques' Les principes fondamentaux de toute assurance sont les suivants: intérêt assurable, bonne foi absolue, faits matériels, indemnisation, preuve du dommage, cause directe, subrogation et contribution

En fin de compte, la réussite d'un service d'assurance aquicole dépend non seulement de l'efficacite et de la qualite de ses services, mais aussi de la formation et de l'existence continue d'un marché de souscription à long terme pour l'assurance des risques inhérents à l'aquaculture, en particulier ceux encourus en ce qui concerne le stock et les responsabilités.

Les procédures existantes du marché de l'assurance sont applicables à nombre de situations aquicoles, mais le libellé de la police d'assurance sur le stock doit tenir compte des intérêts particuliers au stock aquicole, et des problèmes qui se posent également en ce qui concerne la protection des responsabilités aquicoles, notamment la responsabilité produits et les responsabilités maritimes associées aux installations a terre. L'aquaculture est une activité où le risque est considérable. Son stock est exposé à de nombreux périls tels que: pollution, maladie, destruction rendue nécessaire par la maladie, empoisonnement alimentaire, insuffisance de l'approvisionnement en eau, pannes, destruction des filets et des cages, prédation, crues, intempéries, pannes de courant, vol, négligence, tempête, incendie, explosion, tremblement de terre, choc, aéronefs, émeute, et dommages par actes de malveillance. D'une manière générale, la seule assurance stock viable est celle qui donne une couverture 'tous risques'.

Les principaux domaines de la responsabilité aquicole sont: la responsabilité de l'employeur (accidents du travail), la responsabilité civile (maritime et non maritime) et la responsabilité produits. La première concerne l'exposition à un risque standard qui n'est pas particulier aux aquaculteurs. Toutefois, la pisciculture débordant sur le domaine de la mer, la responsabilité maritime imputable aux collisions ou à d'autres dommages provoqués par les radeaux, pilotis, cages, filets, etc., utilisés en aquaculture devient une rubrique plus importante qui nécessite une couverture. La couverture de la responsabilité produits est également importante, car l'activité aquicole peut transmettre les affections à d'autres stocks de poissons, ses produits peuvent causer un préjudice à l'homme, et l'équipement fabriqué peut causer un préjudice ou d'autres dommages à des tiers.

Etant donné que l'assurance aquicole est une nouvelle catégorie d'assurance, un libellé nouveau est en cours d'élaboration pour les polices et il incombe aux pisciculteurs d'examiner la police proposée avec grand soin, notamment en ce qui concerne les moyens d'établir la valeur des animaux aquatiques qui peuvent faire l'objet d'un sinistre Les porteurs d'une police qui subissent des pertes devraient toujours agir comme s'ils n'étaient pas assurés et respecter les procédures stipulées dans la police pour les demandes d'indemnité.

Il est difficile de discuter des coûts de l'assurance aquicole, mais il est recommandé à l'acquéreur de recourir aux services d'un agent ou d'un courtier, qui peut explorer le marché pour y trouver la couverture la plus économique et la plus efficace. La couverture tous risques est recommandée et il peut être économique pour le pisciculteur et intéressant pour le souscripteur que le premier contracte une assurance de groupe.

La gestion des risques, complément naturel de l'assurance, se fixe les tâches ci-après: découvrir les sources éventuelles de risques, evaluer l'ampleur du dommage sur la personne ou sur l'organisation en cas de pertes, et choisir les techniques les plus efficaces pour traiter de tel ou tel risque. Les risques d'entreprise, de type technique, social ou économique, ont des répercussions sur les risques de production, de commercialisation et d'activité financière. Ceux ci se situent tous hors du champ d'application de la gestion des risques Les risques purs, ou administrables incluent: les effets physiques d'origine naturelle et technique (tels que les pannes), les dérogations sociales à la conduite normale et les effets préjudiciables au personnel. L'expérience acquise en matière d'assurance peut réduire les pertes auxquelles sont exposés les pisciculteurs par l'application de la gestion des risques.

Seguro y control de riesgos en la industria acuícola

Extracto

Los seguros, aparte de permitirle al asegurado vivir tranquilo, tienen por objeto distribuir los riesgos y peligros e incluso reducirlos mediante un control de los mismos Los principios fundamentales de todo seguro son: valor asegurable, buena fe, hechos pertinentes, indemnización, prueba de las perdidas sufridas, causa próxima, subrogación y cotización

En último termino, el exito de un servicio de seguro acuícola depende no solo de la eficacia y nivel de sus servicios sino, además, de que se cree y mantenga un mercado de servicios de seguro a largo plazo para los riesgos propios de la acuicultura, especialmente los riesgos de las poblaciones de peces y las responsabilidades ante terceros

Los procedimientos ya existentes en el mercado de seguros pueden aplicarse a muchas situaciones del sector de la acuicultura, pero el seguro de las poblaciones de peces ha de responder a los intereses concretos de las poblaciones cultivadas Tambien las responsabilidades derivadas de la acuicultura, especialmente las debidas a los productos y las responsabilidades maritimas relacionadas con las instalaciones acuícolas, plantean varios problemas. La acuicultura entraña un elevado nivel de riesgos. Las poblaciones de peces están expuestas a muchos peligros, como contaminación, enfermedades, sacrificio de los peces por razón de enfermedad, envenenamiento alimentario, interrupción de los suministros de agua, averias, roturas de redes y jaulas, depredadores, inundaciones, mal tiempo, falta de energia eléctrica, hurto, negligencia, tempestades, fuego, explosiones, terremotos, choques, aeronaves, tumultos y daños causados con mala fe. En general, el unico seguro viable para las poblaciones es el seguro 'a todo riesgo'.

Los principales sectores de responsabilidad en la acuicultura son: responsabilidad del patrón, responsabilidad pública (maritima y no maritima) y responsabilidad por los productos. El primero de estos riesgos no es exclusivo de los acuicultores. En cambio, a medida que las explotaciones piscicolas se internan en el mar, las responsabilidades maritimas debidas a colision u otros daños causados por balsas, pilotes, jaulas, redes, etc., se convierte en un aspecto importante, que es necesario proteger con un seguro Tambien el seguro contra las responsabilidades por los productos es importante, ya que la actividad acuicola puede difundir enfermedades a otras poblaciones de peces, sus productos

pueden causar daños al hombre o el equipo fabricado puede causar daños a terceros u otros daños.

Dado que el seguro acuícola representa un nuevo tipo de seguro, se están redactando nuevas pólizas, por lo que el piscicultor debe examinar la póliza que se le ofrezca con gran atención, especialmente por lo que se refiere a los medios de determinar el valor de los animales acuáticos que puedan ser objeto de reclamación. Los poseedores de la pólizas, en caso de pérdidas, deberán comportarse como si no estuvieran asegurados y observar los procedimientos de reclamación establecidos en la póliza.

Es difícil examinar la cuestión de los costos del seguro acuícola, pero se recomienda que el piscicultor utilice los servicios de un agente o corredor que pueda buscar en el mercado los seguros más económicos y eficaces. Se sugiere el seguro a todo riesgo: la contratación de seguros en bloque puede ser económica para el piscicultor y atractiva para el asegurador.

El control de los riesgos, que representa un apéndice natural de los seguros, se refiere a: descubrir las fuentes de posibles riesgos, evaluar las repercusiones que pueden tener las pérdidas en el individuo o la organización, y elegir las técnicas más eficaces para afrontar los riesgos. Los riesgos del negocio que son de tipo técnico, social o económico repercuten en los riesgos de producción, mercadeo y financiación. Todos estos caen fuera del ámbito del control de riesgos. Entre los riesgos puros o controlables figuran: efectos físicos de la naturaleza, riesgos técnicos (como averías), desviaciones sociales de la conducta normal, y repercusiones negativas en el personal. La experiencia en el campo de los seguros puede reducir las pérdidas de los acuicultores mediante la aplicación del control de riesgos.

1 Introduction

The very existence of a flourishing world insurance market must point to a need for insurance. It does not, however, answer the question, why buy insurance protection?

To many, this question is answered simply: to insure 'brings peace of mind'. Through purchasing a policy of insurance, the financial losses that result from the fortuitous risks and hazards of life are effectively shared with others and reduced accordingly. Such a 'feeling of security' is not to be underrated but it is of secondary importance in the business context where a viable insurance policy represents security of their interest to investors and shareholders, bankers, suppliers of equipment and services, and others financially interested in a business. There are few levels of industry or individual companies to which this does not apply. In the context of aquaculture, even the small operator will find his bank manager more considerate if, accompanying a request for loan facilities, he is presented with evidence that the operator holds valid, secure and appropriate policies of insurance on all the important insurable interests of his operation. With large, sophisticated operations, the situation is exactly the same, except that the capital requirements are bigger and thus the interests of bankers and investors tend to be correspondingly larger and more important to them.

Insurance, however, is not only concerned with the spreading of risks and hazards, it is also vitally concerned with reducing them and a natural adjunct to insurance is the control and management of pure risk, otherwise known as 'risk management'. Risk management is an objective business discipline concerned with the economically viable reduction and, if possible, elimination of risks and hazards. It is practised, naturally, by insurance underwriters who will often warrant that action is taken to reduce certain high risks before granting coverage, and by the specialist departments of insurance brokers and agents and insurance companies whose function is to concentrate on defining, evaluating and dealing with the risk element of many different industries. Insurance is an industry that functions principally in the western world. If aquaculture is to flourish and grow in the western world it is vital that the insurance market accommodates and spreads the risks and hazards of aquaculture. Risk management, however, concerned as it is with the elimination of waste by the reduction and elimination of wasteful risks and hazards, is global in its application.

In this paper the author has dealt with both insurance and risk management in the belief that, together, they will eventually constitute one of the most influential, single, outside contributions made to aquaculture wherever practised.*

2 Aquacultural insurance

2.1 *The basic function of insurance and the rules that govern it*

2.1.1 *The function of insurance is to spread risks.* The most simple statement of the concept of insurance is probably that used in the first Act of the English Parliament regulating insurance, dated 1601: '. . . by means of which policies of assurance it cometh to pass on the perishing of any ship there followeth not the undoing of any man, but the loss lighteth rather easily upon many than heavily upon few . . .'. The Act was, of course, concerned with the insurance of ships from which the modern insurance industry can trace its origins, but the logic that 'the loss lighteth rather easily upon many than heavily upon few' expressed as it is in modern terms as 'the spreading of the risk over many shoulders' is the reason for the existence of an insurance market whose function is to spread risks.

2.1.2 *The fundamental principles of all insurance.* The fundamental legal principles of insurance are so important that an explanation of each is a pre-requisite to any comprehensive paper on insurance.

(*i*) *Insurable interest.* Any party wishing to take out insurance must have an insurable interest in the property or liability for which coverage is required, *ie*, he must benefit by the safety of the insured property or the absence of liability.

(*ii*) *Utmost good faith.* The duty of utmost good faith applies to all contracts of insurance and is permanent. It is the duty to disclose material facts (see (*iii*) below) and is required, equally, of both parties to an insurance contract; inevitably, it is of greater relevance to an insured than to his underwriters. The full facts relating to a risk are usually known, or should be known, by the prospective insured, whereas they are not known by the insurer who is the other party to any insurance contract issued. The responsibility,

*The description is based largely upon the experience gained by the Bain Dawes Group Limited which carried out an extensive study of aquaculture and its prospects in 1973. The findings of this study encouraged further investigation into existing insurance arrangements covering the unusual insurable interests of fish farmers. This investigation revealed an apparent lack of any concerted progress in world insurance markets toward developing new, and adapting existing, insurance techniques to aquaculture's needs. To remedy this apparent gap in the insurance industry's all round service, the Bain Dawes Group formed an independent subsidiary, the Aquacultural Insurance Service Limited (AIS) to provide an insurance service for all parties with a direct or indirect interest in insuring aquacultural risks and hazards. The service was primarily intended to offer advice to insurance brokers and agents on arranging insurance coverage on the aquacultural interests of their clients, and to make available to insuring underwriters and companies information and assistance over such matters as arranging insuring terms, conditions and procedures to apply to aquacultural risks, determining the material facts relevant to fish farming, arranging re insurance facilities and selecting experts in various fields capable of carrying out inspections of aquacultural installations for insurers and assisting them in technical aspects of claims settlement. A complementary risk management service was included

therefore, mainly rests with the insured to observe the duty of utmost good faith in disclosing, in full, all material facts.

(*iii*) *Material facts*. A 'material fact' has been defined in law as: 'a fact that would affect the judgement of a rational underwriter in considering whether he would enter into the contract of insurance, or enter into it at one rate of premium or another.'

There are several points to be made here. Firstly, material facts are not just those that are provided in answer to questions in a proposal form. Secondly, and of greatest importance in the conduct of aquacultural insurance, materiality does not depend on the opinion of the prospective insured. Whether or not a fact is material must be for a court to decide and it can decide that a fact is material after a policy has been issued; usually after a claim has been made.

It may be that a proposer quite innocently breaches the principle of utmost good faith by not disclosing material information — *information that he did not know would have an influence on the rating or acceptance of the risk*. The problem for the fish farmer is to decide what is a material fact and what is not.

It is common in insurance text books to state that material facts include the following:

(*a*) Facts which tend to render the risk proposed for insurance greater than normal.

What is normal in aquaculture? It is an industry where no two risks are alike and the state of its science is somewhat primitive. In the author's opinion, as an example, a material fact of this nature exists when an operator either manufactures his own food, or prepares his own food recipe for manufacture by others. As a further example, the relationship of stocking densities to water volume is a material fact of importance to underwriters. It is, however, a material fact that has yet to be clearly defined in the context of prevailing climatic conditions.

(*b*) Facts suggestive of some special motive for insurance.

In aquaculture, for example, this would relate to aquatic species that were only insured because, for some reason, the insured felt that they were at greater risk than his other stock.

(*c*) Facts necessary to explain the exceptional nature of a risk where in their absence the underwriter would justifiably believe the risk to be normal.

This is a wide-open subject. Many aquacultural operations are in themselves exceptions, though, as other similar operations develop, a norm will be gradually established.

(*d*) Facts which show that the proposer himself is in some sense abnormal.

This is, again, very difficult to relate to aquaculture. As far as general insurance is concerned it would cover, for example, an unfortunate claims experience which might be indicative of accident proneness, or the declination of the risk by a previous insurer. It is generally intended to bring out the moral hazard as opposed to the physical hazard. In aquaculture, in the author's opinion, lack of experience with a certain species would be a material fact that would fall under this heading.

There are many unresolved questions as to what are the material facts concerning any aquacultural operation. Only time will resolve these questions but, as far as the buyer of an aquacultural insurance policy is concerned, there is some comfort to be drawn from the essential point that onus of proof rests with underwriters to prove that a fact is material.

(*iv*) *Indemnity*. Indemnity concerns the compensation of an insured party following a loss. The principle of indemnity is that: 'an insured should, as far as possible, be placed in such a position following a loss, as he would have been in had the loss not occurred'.

(*v*) *Proof of loss*. Proof of loss can be defined as: 'the procedure of demonstrating that a loss falls within the terms of an insurance policy both as to the extent of the loss and its nature'. It is a really critical and most fundamental factor in aquaculture stock insurance; the more so, as the state of the science of aquaculture is relatively unsophisticated. In relation to the 'nature' of a loss, the burden of proving that it is caused by an insured peril rests upon the insured. To comply with the need to provide proof of loss following a claim a policy holder should:

(*a*) keep written stock control records as accurately as the state of the art of aquaculture allows; and

(*b*) keep close track of events as they develop in a claims situation and make every effort to see that causes and actions taken are well documented (see 2.6.3)

(*vi*) *Proximate cause*. This is closely allied to proof of loss in that, through its operation, an insurer is liable under a policy only if any loss or damage sustained is proximately or immediately caused by the operation of an insured peril as scheduled under the cover conditions of a policy (see 2.6.1).

(*vii*) *Subrogation*. This is a subject closely related to indemnity (see (*iv*) above). It is usually defined as: 'the right of an insurer who has paid a claim under a policy issued by him to receive the benefits of all 'rights and remedies' of the insured which will extinguish or diminish the ultimate loss sustained'.

Implicit in this are two points. Firstly, the principle of indemnity would be compromised if the loss having been recovered from underwriters by the insured, the insured also received recompense from a party responsible for the loss. Secondly, the insured must at all times protect the interests of underwriters. Both points are linked and require an insured to carry out such basic procedures as holding responsible third parties liable for a loss by written, registered, letter and duly pursuing recovery of the loss until assigning rights of subrogation to underwriters, following payment of the claim.

The legal right of an insured to recover from any third party is not reduced by the fact that he has been indemnified by his insurers; nor is this legal right one that can be transferred to his insurers. It can, however, legally be assigned, *ie*, insurers can use the insured's name to effect a recovery. Thus, insurers will always require a letter of acceptance to be signed by an insured prior to actually making payment to an insured in settlement of a claim. This letter of acceptance assigns to underwriters themselves the insured's rights of recovery against any third party, in his name.

(*viii*) *Contribution*. This is, again, linked to indemnity and provides for the equitable distribution of a loss among insurers if two or more policies are in effect on the same insurable interest. It prevents an insured, who holds several policies covering the same perils on the same insurable interest, from being indemnified several times over, thereby breaching the principle of indemnity (see (*iv*) above).

2.2 *Paramount insurance problems associated with aquaculture*

Ultimate success of an aquacultural insurance service depends not only on the efficiency and standard of its services but, of paramount importance, on the formation and continued existence of a long-term underwriting market for aquacultural insurance risks, particularly the risks to stock and liabilities. There would be no long term insurance market unless underwriters made a profit from spreading the risks and hazards of aquaculture (see 2.1.1.).

Rigid adherence to the underwriting profit criterion would necessitate recommending to insurers only the most carefully selected and 'best' risks. If this were done, the benefits and advantages of insurance coverage would be denied to many engaged in the aquacultural industry, besides which, the whole problem of what is 'the best' aquacultural risk has still to be determined.

The history of insurance contains many examples of how the insurance industry has met and solved the problems in insuring industries founded on new and often high-risk technologies, *eg*, offshore drilling, chemical, aviation and shipping industries. In every case, it has done so by resorting to very old but well tried principles (see 2.1.2) and by anticipating many of the problems through careful analysis of relevant information and material facts. Further, it has been achieved by developing and adapting its procedures (not least of which is the discipline of risk management) in the light of practical experience.

2.3 *The special insurance needs of commercial aquaculture*

One of the first tasks of AIS was to compile a list of the basic insurance coverages that should be included in the portfolio of any commercial operation exploiting aquaculture on a multi species basis. Standard policy wordings for each type of coverage listed were assembled and their individual suitability to a commercial aquacultural situation examined. The survey showed that, in the majority of instances, existing policy wordings were quite suitable to aquacultural situations. The risks of fire and other major perils to onshore and offshore installations and their contents, of theft and breakdown of machinery and equipment, to money, office contents and other items, in motor vehicle, employers' liability and public liability (as distinct from products liability) exposures, to name but a few, major, insurable interests, can all be adequately protected under existing insurance market procedures.

The survey also showed, however, that existing stock insurance wordings did not cater for the peculiar and special insurable interests of aquacultural stock (see 2.4). Furthermore, it showed that when the relevant material facts of aquaculture were considered and later disclosed to insurers, problems arose in the area of protecting aquacultural liabilities, particularly products liability [see 2.5.2 (*iii*)] and the marine liabilities [see 2.5.2 (*u*) (*a*)] associated with offshore installations.

2.4 *Aquacultural stock insurance and perils*

The most important asset for an aquaculturist to protect is the stock of particular species to whose health and growth a company's entire expenditure of effort and capital is completely devoted and upon which its profitability entirely depends. If anything happens to prevent that product reaching its market, then all effort and expense is wasted. It is, thus, clear that the most important insurance policies in the portfolio of any commercial aquacultural operation are those that protect the loss of its stock. All the more is this the case when the extremely delicate nature of aquacultural stock is taken into account.

People in and associated with aquaculture are the first to admit that it is a high risk business. There are few other stock-rearing industries that are so exposed to such a rapid and extensive loss of stock from so many varied causes. The dependence of stock on water adds a totally new dimension to livestock insurance and creates a whole series of problems that are entirely different from those problems associated with the air breathing animals that are familiar to most insurers.

Aquacultural stock is open to loss or loss of value from a most formidable number of very different perils which may broadly be listed as follows: (*i*) pollution; (*ii*) disease; (*iii*) slaughter made necessary by disease; (*iv*) food poisoning; (*v*) failure of water supply (from natural causes and climatic conditions, blockages and breakages); (*vi*) breakdown of equipment and machinery; (*vii*) net rupture and cage failure; (*viii*) predation; (*ix*) flood; (*x*) cold weather; (*xi*) power failure; (*xii*) theft and pilferage; (*xiii*) negligence; (*xiv*) storm and tempest; (*xv*) fire; (*xvi*) explosion; (*xvii*) earthquake; (*xviii*) impact; (*xix*) aircraft; (*xx*) riot; (*xxi*) malicious damage.

Many of the perils listed above are inter related and as yet undefined. Therefore, whilst it is common practice in other branches of insurance to provide what is called 'named-perils' coverage (*ie*, insurance against certain listed perils only), the dangers to the aquacultural operator of insuring his stock on a named perils basis, where the definitions of the specific perils named are new and untried, is very great due to the likelihood of misinterpretation by either or both parties to an insurance contract. Such coverage is of dubious value as the burden of proof of loss is on the insured [see 2.1.2 (*v*)].

The difficulty of defining a named peril is easily demonstrated using 'pollution' as an example. The author has been asked on many occasions to arrange pollution coverage on stock. Every time the same questions arise. What is pollution? How can it be defined? It must be borne in mind here that a policy of insurance is intended to be evidence of a contractual agreement between insurer and insured and, as such, put into effect the exact intentions of both parties. Looking into the Oxford Dictionary, the following definition is found: 'pollute . . . destroy the purity . . . of; make (water, *etc*) foul or filthy'. Now, might not the 'purity' of water be destroyed if infested by disease organisms? If so, how can a contract be drawn up between insurer and insured which expresses a mutual understanding by both parties of what is meant by 'pollution'. It would not be the intention of insurers, in granting pollution coverage only, to cover disease risks. The logical step, therefore, is to produce a definition of pollution that specifically excludes disease as a destructor of the 'purity' of water.

The author submits, that to do this would immediately prejudice the position of the insured as it is entirely possible for a polluting substance (*eg*, quarry finings) to pass through a fish farm without causing death of stock immediately but, nevertheless, causing injury (*eg*, gill infection) to fish who later die from injury induced disease. The cause of the loss would thus appear to be disease and, therefore, would be excluded under the policy. The insured's chance

of proving otherwise would depend, probably, on his ability to prove that the injurious substance had passed through the system, and that it had caused the injury that had led to the disease that had led to the loss. Given the present state of the science of aquaculture, the odds are heavily stacked against the insured doing this.

It is the author's submission that, however pollution is defined, and there are several ways that this can be done, claims will arise under all definitions of pollution that will lead to disputes between underwriter and insured and, therefore, it is unwise for fish farmers to purchase coverage where pollution is a named and defined peril.

As a general rule, the only viable stock insurance is full 'All Risks' coverage, though it is certainly reasonable to work in reverse and exclude individual perils from broad All Risks coverage. The onus is then transferred to insurers to prove that a particular loss is inadmissable because a specific peril that caused it is excluded. By using exclusions in conjunction with All Risks coverage the best interests of the policy holder are served in difficult and borderline cases and an insured can be sure of where he stands.

2.5 *Aquacultural liabilities*

2.5.1 *General or third party legal liability*. It is important to stress that the law of individual countries must always be taken into account when considering questions of liability. It is also important to consider aquacultural liability alongside the basic insurance principle of subrogation [see 2.1.2 (*vii*)] and the protection of insurer's interests that is implicated therein.

In most countries a personal or corporate liability usually stems from an act or omission which causes injury, disease, loss or damage to a third party and which can be proved to be the result of negligence. Legal codes vary from one country to another and may be based upon common or statute law. This is the basic position but it can be amended by agreement between relevant parties under contractual arrangements.

2.5.2 *The main areas of aquacultural liability*. There are three main categories of liability, two of which are particularly important by virtue of their special implications in an aquacultural situation. These are discussed below:

(*i*) *Employers' liability* (*workman's compensation*). This is a standard liability exposure which does not hold any great problems for the fish farmer, providing the material facts surrounding his business are disclosed to insurers. It is possible that in time, maricultural operations may prove from the insurers point of view, slightly more hazardous particularly if divers are regularly employed. However, it should be possible to place employers' liability risks without too much difficulty.

(*ii*) *Public liability*

(*a*) Marine liability in mariculture

As fish farming encroaches farther into the sea and closer to navigational channels, it is very important to be aware of the law of the sea in relation to collisions.

A shipowner under Marine Law is entitled to limit liability for third party personal injury or property damage to approximately US$ 300/GRT subject to a minimum contributing tonnage of 300 tons. Therefore, the small boatowner (and many maricultural operations use such boats) should be adequately protected by purchasing some US$ 100 000 liability insurance for any one accident. The privilege of a shipowner being able to limit his liability presumes that the act of negligence arises without the fault or privity of the owner.

Unlit rafts or other offshore structures (even a pole for mussels or oysters) could be considered a danger to navigation unless the appropriate authorities in the country of the territorial waters concerned have approved such structures and their location. A fixed offshore structure, be it a pole or a platform would, in our view, never be deemed to be a vessel and, therefore, its owner would have no method of limiting his liability in respect of the full amount of damage caused. The maricultural operator, therefore, faces unlimited liability in this respect. Rafts might, in certain circumstances, be deemed to be vessels but Marine Law is not usually specific on this point and inquiries into the subject should be made by every operator in the country in which he operates.

Up to now, the majority of fish-farming structures, cages, nets and rafts, have remained close inshore and have usually been small in size. Now that the scope of fish farming is increasing some of the structures or platforms may increase considerably in size and approach the size of small oil drilling rigs. It is known there have been instances of unlit rigs being held responsible for collision damage with a vessel. In addition to this, a raft or structure may break away in a storm and, should it become entangled with, for instance, a pier or moored boats, could cause serious damage which may be directly attributable to its owner. This and the other marine liabilities should be adequately protected by insurance.

(*b*) Non marine liabilities

The non-marine liabilities of an aquacultural operation are really no more unusual and certainly no greater than in other industries and it is really the level of liability insurance that must concern the operator. This depends to a great extent on the country he is operating in and on such material facts as whether or not the public are encouraged to visit his farm. It is unlikely that any special non-marine public liability hazard will emerge and make aquaculture a particularly difficult industry for insurers to handle, and there should be no lack of insurers willing to offer this coverage to operators at a reasonable cost.

(*iii*) *Products liability*. Any manufacturer of any product needs to carry products liability coverage: as fish farmers are now producing primary products it is most important that they too carry adequate insurance protection of their liability in this area. There are a number of aspects to this question which should be considered: they relate primarily to the nature of any operation. Some farmers produce only small fish for sale to on-growers or for the stocking of sport fishing lakes: other farmers only on-grow stock for the table market: a third type of operation does both of these and some farms even manufacture equipment for sale to others as a by-product of their main business.

In the context of a very active aquacultural industry in which fish are continuously being moved around, hatcheries and suppliers of livestock increasingly face the possibility of being held liable for loss or damage, *etc*, as a result of their supplying diseased fish to another farm or to a sport fishery. For such hatcheries, a products liability policy is a most important item in their insurance portfolio.

On-growers, too, face a products liability exposure. Botulism is a word which should not be especially associated with fish farming any more than with other

stock-rearing industries like pig or poultry farming. However, it is an example of an on-grower's products liability exposure because, if it can be proved that fish from a certain origin contain the organisms *Clostridium botulinum*, the on-grower could be held responsible if death or disability results from eating his product. Botulism is not the only hazard associated with farmed aquatic creatures. Cholera virus has been found in molluscs and they have been designated as a source of outbreaks of that disease in human beings. It is well known that certain metals, such as mercury, can accumulate in fish and cause severe disability or death to consumers, as can other chemicals. The Minamata disaster that occurred only a few years ago, when the Chisso Corporation's mercury effluent caused widespread death and even congenital disease through the agency of the fish eaten by the inhabitants of Minamata, provides a good example of this. In all these situations, the fish farm producer can be held responsible and must protect himself with a good products liability insurance policy.

Finally, manufacturers of equipment will undoubtedly be held responsible if their equipment is found to be the cause of injury, disease, loss or damage to a third party, and they should protect themselves accordingly.

2.6 *Aquacultural insurance policy wordings*

2.6.1 *Covering conditions.* An insurance policy is evidence of a contract between an insured and his insurers. The over-riding importance of a policy is that it should put into effect the intentions of the parties to the contract it evidences. It must, therefore, be a carefully worded document expressing accurately these intentions or it becomes the cause of contentious disagreement between an underwriter and an insured that it should obviate.

Insurance wordings for different established classes and types of insurance have evolved and developed in the light of practical underwriting experience and legal decisions. Aquaculture represents, in certain repects, an entirely new class of insurance and, as a result, new insurance policy wordings have been and will have to be developed and changed to meet its needs. This change and development is inescapable and, by the same token, because aquacultural policy wordings are so new and untried, it is most important for the potential buyer of aquacultural insurance to examine closely the terms and conditions of the policy wordings offered to him.

Any fish farmer would be very unwise to accept any insurance quotation offered to him, unless it comes from a company specializing in aquacultural insurance and without first receiving a full written copy of the exact terms and conditions being offered. He must then consider whether or not those terms and conditions express accurately what he himself understands will be covered by the policy he is purchasing. In order to analyse the relevance of an offer of insurance coverage, a fish farmer can do no better than sit down and examine the offer in terms of those risks, perils and hazards (see 2.4) that he alone knows his business is open to, and ask himself the same questions of every peril: is it covered by this wording? If he is at all unsure of the answer then he must question those who provided the insurance offer accordingly, and he would be well advised to obtain their answers in writing.

2.6.2 *Indemnity terms.* Though coverage of particular perils and hazards must be clearly and unequivocally dealt with in a policy wording, of equal importance are the terms of indemnity offered under a policy (see 2.1.2 (*v*)).

A viable policy of insurance must include a section expressing the agreed intentions of insured and insurers as to the financial or other procedures for compensating an insured following a loss. If aquacultural stock is involved, there must be in a policy a means of establishing, without dispute, the value of different sizes and species of the aquatic animals that are likely to be the subject of a claim. These procedures must reflect the principle of indemnity and be expressed in such a way as to allow practical settlement of a claim.

2.6.3 *Claims procedures and standard rules.* A policy of insurance, particularly one covering aquacultural stock, should contain instructions on how an insured should act in respect of a loss. Such instructions may or may not be very specific, but, whatever they say, they are unlikely to give a policy holder all the guidance he needs, particularly as the policy itself may not be readily available while a claim is actually happening. Any policy holder faced with a loss situation should always observe two rules: (*i*) act as though uninsured; and (*ii*) observe the claims procedures laid down in the policy.

If an insured acts as though uninsured in a loss situation he will naturally do all he can, within reason, to ameliorate the situation; if he is held liable for some action or negligence, he will deny liability and if his business assets are hazarded he will do all he can to minimize or prevent damage or loss and hold liable any party who may be responsible for such damage or loss. Acting in such a manner he will, thus, effectively protect the interests of his insurers which he is required to do and, once the immediate loss situation has passed, he can turn to his insurance policy and comply with the claims procedures laid down therein.

2.7 *Premium costs*

2.7.1 *Cost of general insurance coverages.* It is impossible to give any precise guidance on this subject. It is up to the insurance buyer to obtain quotations on his portfolio from different sources. The author can only recommend that every insurance buyer should use the services of an insurance broker or agent whose task is to search the insurance market for the most economical source of coverage. This service is normally provided free and, aside from providing the best means of searching the insurance market for the most cost effective insurance coverage, it offers a most important source of advice on what coverage is needed to best suit the particular buyer's situation.

The author strongly advises against going direct to an insurance company because the buyer is only able to obtain coverage according to the terms and cost offered by that one company. He can never be sure that he is being offered the best coverage available, or that it is provided at the most competitive cost, or that all his insurable interests are protected.

2.7.2 *Cost of aquacultural stock insurance.* This subject needs to be treated separately because of the novelty of insuring aquacultural stock, and there are a number of general aspects on this subject which should be borne in mind by buyers of aquacultural stock insurance.

Firstly, the actual number of insurance markets offering stock insurance is very limited (see 2.3) and, as a result of

this, the range of choice of the prospective buyer as regards premium and coverage is also limited. Secondly, and of greater significance, insurers are, inevitably, engaged in finding out what are the correct premium levels and base rates for given degrees and types of stock coverage (see 2.2). This is a fundamental part of the evolution of aquacultural stock insurance. All that can be said is that All Risks of Mortality coverage has been successfully arranged for the stocks of a considerable number of small and large aquacultural operations, farming quite a number of different species, at premium levels which have proved entirely viable economically. Only time and experience will tell if the premiums currently being offered are of such a level as to prove profitable to underwriters, or whether they need to be raised or can even be reduced.

There is one further aspect of cost which should be mentioned, concerning bulk buying. Ordinary farmers have often found it economical to purchase their general requirements centrally, through co-operatives. This cuts down distribution costs and middlemen's commissions, and insurance, like commodities, comes cheaper in bulk. Aside from the administrative savings, a sizeable block of insurance business is attractive to underwriters because of the 'law of large numbers'. The offer of an entire group's aquacultural business in one package enables the insurer to calculate more exactly the catastrophe element in the particular package of risks and, as the premium volume is much more significant, underwriters are presented with an investment income that tends to be overlooked where individual farms are concerned. A third advantage arises in that the individual underwriter's share of the overall risk can be increased due to the greater spread. His reinsurance provisions can also be reduced, and purchased more cheaply.

2.8 *The insurance market for aquacultural stock*

The world insurance market for aquacultural stock insurance can only, at best, be described as tenuous, disparate and very short of the capacity needed to cover the potential maximum sums insured that may be required for aquacultural operations in the near future. But, slowly but surely, the market for aquacultural stock is widening, thus the existing, somewhat restricted, insurance market will hopefully soon be a thing of the past.

To a very great extent, the development of an insurance market for aquacultural stock lies in the hands of fish farmers themselves and the authorities who govern them. It is up to them to support the efforts being made on their behalf which, if successful, will stimulate the interest of insurers generally and thus contribute to the development of the competitive market for aquacultural stock which is so very much in the interest of the development of aquaculture itself.

3 Aquacultural risk management

3.1 *Risk management, a science in its own right*

The ultimate efficiency of aquaculture and indeed the scope for its continuance and expansion can be shown to depend upon achieving and maintaining an optimal level of return of the mature product over the input of eggs or juveniles. However, the folly of making safety and the saving of waste paramount at the expense of cost effectiveness can be fully demonstrated. The techniques of getting these two diverse factors in balance are bound up in 'risk management'.

Risk management concerns itself with the application of three criteria: (*i*) discovering the sources from which risks may arise; (*ii*) evaluating the impact on the individual or organization if a loss should occur; and (*iii*) selecting the most effective technique(s) to deal with the risk.

Within these criteria there exists a science in its own right. Many books have been written on the subject of risk management, and in a paper of this length it is not possible to deal fully with the subject but only with basic risk management in aquacultural terms in the context of reducing and eliminating risks and hazards and thereby waste in aquaculture.

3.1.1 *Business risks as opposed to pure risks.* There is a distinction between business risks, or the factors in management sciences, and pure risks. Broadly, business risks can be split into a number of headings as follows: (*i*) technical (*eg*, snags in new processes, lack of knowledge); (*ii*) social (*eg*, changes in consumer tastes); (*iii*) economic (*eg*, inflation, change in level of economic activity, actions of competitors; (*iv*) political (*eg*, nationalization, political unrest, war, trade restrictions).

All of the above have a bearing on: (*v*) production (*eg*, interruption, change in costs, problems of raw material supply); (*vi*) marketing (*eg*, errors in forecasting demand, loss of markets to competitors); (*vii*) financial (*eg*, bad debts, changes in availability or cost of credit).

All these headings in the context of the examples shown are ones which fall outside the scope of risk management and, of them, number (*i*) 'technical', must be the most relevant as far as aquaculture is concerned. It is important that it be recognized as falling outside the scope of risk management: it could perhaps, as far as aquaculture is concerned, be better termed 'fish management'.

3.1.2 *Pure, or manageable, risks.* Risks that can be managed that fall outside business risks can be broadly categorized under the following headings and these should be considered alongside the list of perils shown under section 2.4: (*i*) physical effects of nature (*eg*, wind, storm, earthquake, flood, drought); (*ii*) technical (*eg*, breakdown of plant, failure of safety devices, hazardous processes); (*iii*) social deviations from expected standards of conduct (*eg*, theft, fraud, riot, negligence); (*iv*) personnel (*eg*, death, sickness, injury, working conditions).

It can be seen that all the risks and hazards generalized under these headings can, in some way, be reduced or obviated and all have significant implications in aquaculture.

3.2 *The contribution of insurance experiment to risk management in aquaculture*

Responsible insurers have always put their experience at the disposal of industry in various ways, since the improvement of insurable risks benefits both parties. In dealing with this subject it is important to stress that insurance experience should be available to all of aquaculture, regardless of geographical barriers or political persuasions. The prevention of waste which is synonymous with risk management must be, and is, available to all, as it rightly should be.

In the insurance context, there is a great deal that fish farmers can do to reduce and eradicate losses by adopting risk management practices and procedures, thereby benefiting, firstly, from increased efficiency, and secondly, from reduced insurance premiums.

But what are those 'practices and procedures'? Who better to ask than the insurers who, in the western world are covering the risks and also paying for the losses of aquaculture? Who, but insurers and their brokers and agents, can have such a comprehensive knowledge of the losses that can occur to aquacultural stock, why they occur, and thus, how they can be prevented, reduced or avoided? There is no greater outside contribution to be made to aquaculture than that contribution that can, and will, be made by the insurance industry in the field of risk management. History shows time and again that whenever and wherever the insurance industry has been called on to exercise its functions of spreading risks and hazards it has always turned the experience it has gained into practical ways of preventing the occurrence of those losses it is required to pay for, and ways of limiting them. In the marine and aviation fields, in fire and allied perils insurance, even in life insurance, the insurance industry has continually strived to maintain and improve standards that will lead to lower losses. The same is already happening in aquaculture.

4 Conclusion

The increase in the world's population and the static catch of various species renders the development of aquaculture unquestionable. Nevertheless, the increasing success of fish farming will introduce a new style of competition and eventually margins will be brought under pressure. We have seen this happen in poultry farming and we have seen the huge growth and, therefore, risk increase in such enterprises.

Huge concentrations of values make for good, economic administration, but they lead to big fires, big disease losses and, without fantastic planning expertise and care, extreme vulnerability to machinery breakdown. A mistake by a fish food manufacturer can destroy 10 million farmed fish in one disaster and, as the industry flourishes and grows more sophisticated, still bigger losses will arise. Insurance compensation has saved many great companies and vigorous, flexible, sound insurance facility merits the support of the industry of aquaculture.

Risks, Mortality and Insurance of European Trout Farms

Ian S. MacFarlane and R. Louise Varley

Abstract

The causes of mortality resulting in a loss of annual production of more than 5% are examined for 25 trout farms in the British Isles, France and Spain. All causes of mortality on 16 English and Scottish trout farms are also examined. By far the most common cause of large losses was water pollution, which resulted in 29·10 tons of lost production per 1 000 tons. Other causes accounted for only 5·22 tons of lost production per 1 000 tons. Small losses occurred more frequently than large (19·12 and 1·49 incidents per 1 000 tons of production respectively) and their greatest effect was on small sizes of trout. The most common causes of small losses were systems and husbandry/management failures. The pattern of loss changed through the production system, and the number of fish lost decreased as the fish grew.

The risk of small and many large losses can be reduced by improved management. Some large losses are less easily controlled and mortality insurance may reduce the financial risks involved. Accumulation of data on causes of mortality will enable risks to be reduced during the planning stages, by improved management of existing farms and by continued provision of mortality insurance at a cost acceptable to the trout farmer and the underwriter.

Stations européennes de truticulture: risques, mortalité et assurances

Résumé

Les causes de la mortalité, qui provoque une perte de production annuelle dépassant 5 pour cent, sont examinées pour 25 stations d'élevage trutticole aux Iles Britanniques, en France et en Espagne. On examine également toutes les causes de mortalité dans 16 entreprises trutticoles en Angleterre et en Ecosse. La pollution des eaux est de loin le facteur le plus important de mortalité et est responsable de la perte de 29,10 pour mille, alors que toutes les autres causes n'ont fait perdre que 5,22 pour mille. Les incidents mineurs ont été plus fréquents que les accidents graves (19,12 et 1,49 pour mille de production, respectivement) et leur effet s'est fait sentir plus particulièrement sur les truites de petites dimensions. Ils ont été le plus souvent provoques par des pannes de matériel et des déficiences dans les méthodes d'élevage ou de gestion. Les problèmes entraînant des mortalités de poissons varient suivant le système de production, et le nombre de poissons perdus diminue à mesure de leur croissance.

On peut réduire les risques de petits incidents et souvent même les cas d'accidents graves en améliorant la gestion. Il est plus difficile d'éviter certains gros dommages et l'assurance contre la mortalité est susceptible de limiter les risques financiers. Le rassemblement de données sur les causes de mortalité permettra de réduire les risques en cours de planification, par l'amélioration de la gestion des stations existantes et par la possibilité constante de s'assurer contre la mortalité à un coût acceptable tant pour l'éleveur que pour la compagnie d'assurances.

Riesgos, mortalidad y seguros en las granjas europeas para truchas

Extracto

Se examinan las causas de mortalidad, que determinan una pérdida de la producción anual de más del 5 por ciento, en 25 granjas para truchas de las Islas Británicas, Francia y España. Se examinan también todas las causas de mortalidad en 16 granjas para truchas de Inglaterra y Escocia. La causa más frecuente de pérdidas importantes resultó ser la contaminación del agua, que es causa de pérdidas de producción de 29,10 toneladas por cada mil toneladas. A las demás causas se debe solamente una pérdida de 5,22 toneladas por cada mil de producción. Se observó una mayor frecuencia de pérdidas pequeñas que de pérdidas importantes (19,12 y 1,49 casos, respectivamente, por cada mil toneladas de producción) y su efecto se apreció sobre todo en las truchas de pequeña talla. Las causas mas frecuentes de perdidas pequeñas son las deficiencias de los sistemas utilizados y de la 'crianza/manejo'. El patrón de las causas de las perdidas cambió a lo largo del sistema de produccion y el número de peces que se pierde disminuye a medida que los peces crecen.

Es posible reducir los riesgos de pérdidas pequeñas y muchas pérdidas mayores con una mejora del manejo. Algunas perdidas importantes son menos fáciles de controlar, y los seguros contra la mortalidad pueden reducir los riesgos financieros que entraña. La acumulación de datos sobre las causas de mortalidad permitirá reducir los riesgos durante las fases de planificación gracias al mejoramiento del manejo de las granjas para truchas y a la disponibilidad de seguros contra la mortalidad de las truchas a un costo aceptable para el truticultor y el asegurador.

1 Introduction

Trout farming in Europe has undergone a transition during the last ten years, from a relatively small industry centred in Denmark and producing some 10 000 tons per annum to an industry producing in excess of 50 000 tons per annum. In some cases, this expansion has been accompanied by an intensification of farming methods, with a trend toward culture of high densities of trout within expensive production facilities. There has also been a development of more professional attitudes toward the operation of trout farms, and an increased awareness of the risks involved.

2 Risks and causes of mortality

Risks in trout farming may be classified as technical,

technological or price related. Technical risks are those associated with the production of the fish, particularly biological problems such as the determination of correct stocking densities and feeding methods, maintenance of adequate standards of hygiene, prevention and treatment of disease, and control of predation. Problems of pollution and water quality, and of design and construction of the facilities, and the operation of the system, may also be included. The risks covered in this paper fall into this category.

These may be distinguished from those risks associated with technological development, which, by the introduction of new construction materials and methods, can make existing enterprises less cost effective. Price-related risks are those connected with the markets for raw materials and finished products, which affect the ability of the trout farmer to produce fish at a profit.

Most trout farmers expect to lose a percentage of the stock through genetic, competitive or environmental factors, and production is planned allowing for this 'normal' mortality rate. Such losses occur at a fairly predictable low level throughout each of the production stages, and are manifested in lower apparent food conversion efficiency than would be the case without mortality.

The data in this paper relate to occasional incidents of high mortality due to one or more identifiable causes. The importance of such incidents to the trout farmer depends on their frequency and scale relative to the 'normal' mortality rate. Some trout farmers may expect a certain number of incidents of a more dramatic nature, and production may be planned to allow for these as well as for 'normal' losses. The larger catastrophic incidents can not be predicted or planned for, and frequently have a very damaging effect on the commercial viability of the individual trout farm.

There is at present little information on the major causes of mortality in European trout farming. Berge (1969) gives the reasons for losses on Norwegian fish farms, and shows that losses of individual fish are greatest during their first winter, decreasing as the fish grow and become less vulnerable to environmental stress. In the Federal Republic of Germany, pollution and disease are the major causes of loss in freshwater fish farming (Reichenbach Klinke, 1970). The Norwegian Business School (1971) gave the major causes of losses in 43 incidents for fish cultured in the marine environment as: disease (27·9%), climate (18·6%) and faulty construction (16·3%). Webber (1973) described and classified the risks in aquaculture, but gave no quantitative information on the causes of mortality. Shepherd (1973) discussed losses as a variable cost of production in trout farming. He gave some information on 'normal' expected losses, which are often implicit in feed costs, and differentiated these from higher losses against which insurance cover may be offered under various categories.

3 Insurance in trout farming

The ability of underwriters to provide effective insurance cover depends upon a knowledge of the inherent technical risks of trout farming, and an accurate assessment of the financial losses resulting from accidents.

Mortality insurance may be provided against various infectious diseases, against pollution and malicious poisoning, and against other losses if they are due to definite identifiable causes or are incurred within a stated period of time, *eg*, 24 hours. The premium may be between 1% and 20% of the maximum value of the stock at any one time, depending on an assessment of the risks on an individual farm. This premium may be reduced if a franchise or excess is included, whereby claims are met only if losses exceed a certain predetermined level or percentage of the stock.

4 Materials and methods

Information was collected from two sources (described in (*i*) and (*ii*) below), and the two sets of data were analysed separately. All farms from which data were obtained are included, except where inconsistencies were found in replies to questionnaires. In some cases it was possible to verify data by personal visits and for purposes of analysis it is assumed that all data are reliable.

(*i*) Group A: Data were obtained from proposal forms completed by European farmers wishing to purchase mortality insurance cover. Applicants were asked to give full details of any losses which had occurred on their farms. Of the 25 farms sampled, 9 were within the British Isles, 13 in France and 3 in Spain. Table I gives some details of the types of farms represented. All use freshwater supplies only, and most produce only rainbow trout (*Salmo gairdneri*), and, in fact, rainbow trout comprise more than 80% of the total production from all farms. Their annual production ranges from 8 to 120 tons.

(*ii*) Group B: Data were also obtained by the circulation of questionnaires to British trout farmers requesting information on the size and type of farms, and details of magnitude and causes of losses during the previous 3 years. The sample comprised 16 farms in England and Scotland, producing both rainbow trout and brown trout (*Salmo trutta*) for the table market and for restocking purposes. Table II gives details of the types of farms. Farms 1 and 11 in Table I correspond to numbers 46 and 7 in Table II. These two farms were the only ones from which both sets of data were obtained.

5 Results

The incidents considered in Group A were those which resulted in loss of more than 5% of the total value of the current year's production.

The 25 farms in Group A represent a total of 8 075 tons of production during the entire period for which records are available. During this period, 10 of the farms were affected by 12 separate incidents, *ie*, 1·49 incidents per 1 000 tons or production. Actual losses of production due to these incidents totalled 277·1 tons, *ie*, 34·32 tons per 1 000 tons of production, giving an average of 23·09 tons lost per incident. In only one case was there a total loss; this was due to pollution, and contributed 80 tons to the total mortality recorded.

Where losses were confined to small fish, sometimes sufficient numbers survived so that little or no final production was lost and restocking was unnecessary. This indicates that the trout farm was deliberately overstocked with fry on the expectation of a reduction in numbers during the ongrowing stages, either through incidents of this type or by grading and culling. In other cases, the number of fish surviving was insufficient to maintain production but restocking with fish from an outside source was possible so

TABLE I
PRODUCTION DATA OBTAINED FROM TROUT FARMS IN GROUP A

Unit number	*Type of pond used for fattening fish*	*No. of years farm in operation (years for which records available)*	*Approximate annual production (tons)*	*Total no. of tons produced during the years for which mortality records available*	*No. of incidents causing mortality during years for which records are available*
1	Circular	1 (1)	8	8	1
2	Circular	4 (4)	25	100	1
3	Earthen	2 (2)	20	40	1
4	Earthen	4 (4)	40	160	2
5	Earthen	3 (3)	25	75	-
6	Earthen	26 (26)	12	312	-
7	Circular and Earthen	3 (3)	20	60	-
8	Circular	1 (1)	35	35	-
9	Earthen	17 (17)	70	1 190	-
10	Earthen raceway	6 (6)	30	180	1
11	Earthen	6 (6)	120	720	1
12	Concrete raceway	5 (5)	100	500	1
13	Concrete raceway	17 (3)	12	36	-
14	Concrete raceway	16 (3)	8	24	-
15	Concrete raceway	6 (6)	120	720	1
16	Concrete raceway	3 (3)	70	210	-
17	Concrete raceway	18 (18)	55	990	-
18	Concrete raceway	17 (17)	20	340	-
19	Concrete raceway	6 (6)	70	420	
20	Concrete raceway	17 (17)	40	680	-
21	Concrete raceway	5 (5)	60	300	2
22	Concrete raceway	15 (15)	15	225	1
23	Concrete raceway	15 (15)	20	300	-
24	Concrete raceway	3 (3)	50	150	
25	Concrete raceway	10 (10)	30	300	-

TABLE II
PRODUCTION DATA OBTAINED FROM TROUT FARMS IN GROUP B

Unit number	*Type of pond used for fattening fish*	*No. of years farm in operation (years for which records available)*	*Approximate annual production (tons)*	*Total no. of tons produced during the years for which mortality records available*	*No. of incidents causing mortality during years for which records are available*
1	Circular	1½ (1½)	50	75	1
3	Earthen	94 (3)	40	120	1
4	Brick raceway	4 (3)	110	330	6
5	Circular and floating cage	3 (3)	12	36	5
6	Circular	3 (3)	40	120	1
7	Earthen	8 (3)	120	360	1
8	Earthen	3 (2)	50	100	6
35	Earthen raceway	90 (3)	50	150	1
37	Earthen	4 (1)	2	2	
39	Earthen	75 (1)	15	15	1
41	Earthen	2 (2)	5	10	5
44	Earthen and Circular	68 (3)	120	360	-
45	Circular	2 (2)	9	18	1
46	Circular	½ (½)	8	4	1
61	Earthen	5 (3)	40	120	2
81	Circular	3 (3)	7	21	3

Group A covers the large, insurable losses, whereas Group B involves mainly small incidents.

that actual production losses were minimized although financial losses might have been considerable.

The 16 farms in Group B represent a total of 1 841 tons of production during the entire period for which records are available. During this time, 14 of the farms were affected by 35 incidents resulting in loss of stock, *ie*, 19·12 incidents per 1 000 tons of production. Incidents ranged in magnitude from losses of 20 kg to 2 tons involving fish of all sizes from fry of 1 g unit weight to potential broodstock weighing 400 g each.

The information obtained from most farms in Group B was insufficiently detailed to allow calculation of actual losses of production. The numbers, weight, and value of losses of fish of different sizes are given in Table III. In many cases, the weight is an approximation from length data and values given are replacement and not production costs. They are based upon average ex-farm prices in June 1975 in the UK, and converted to US dollars at the current exchange rates. They are approximations only and confidence limits of ±25% should be assumed.

The greatest losses by number of fish and by value

TABLE III
LOSSES IN DIFFERENT WEIGHT GROUPS OF TROUT – DATA FROM GROUP B ONLY

Weight group (g)	*Number of fish lost*	*Total weight (tons)*	*Approximate 1975 value (US$)*
< 5	2 094 000	5·5	75 000
5–30	193 800	4·5	34 000
30–100	157 800	8·5	32 000
100–200	75 800	9·1	27 000
>200	12 000	2·7	8 000
Total	2 533 400	30·3	176 000

occurred amongst the smaller groups of trout but loss by weight was greatest in the 100–200 g group. These differences are due to small fish being more valuable, weight for weight, than large fish.

The number and percentage of incidents attributable to various primary causes, for both sets of data, are shown in Table IV. Causes of loss are assigned to several categories which, to some extent, are arbitrary and overlapping. Thus, a blockage of part of the water system might be due to a design fault (systems failure) or to negligence or management error (husbandry/management). Where interactions occurred (*eg*, high water temperature and overfeeding), losses were attributed to what was regarded as the major predisposing cause of loss. The categories shown in Table IV are: (*i*) Systems failure: all losses due to faults of design, engineering, construction, choice of materials and fittings, and standby facilities. This category includes blockages of the system, mechanical breakdown, power failure, breakage and structural failure; (*ii*) Husbandry/management: all losses due to negligence, accident, lack of experience, or faults of judgement on the part of those responsible for the fish; (*iii*) Infectious disease; (*iv*) Climate and site selection: flood, drought, excessively high-water temperatures, freezing, storm damage, deoxygenation by natural factors (*eg*, algal bloom and decay); (*v*) Pollution of the water; (*vi*) Pollution of the food; (*vii*) Vandalism, theft, and other malicious acts; (*viii*) Unspecified.

TABLE IV
BREAKDOWN OF LOSS INCIDENTS BY CAUSE IN GROUP A AND GROUP B

Cause	*Group A*			*Group B*		
	a	*b*	*c*	*a*	*b*	*c*
Systems failure	1	0·124	8·3	10	5 461	28·5
Husbandry/management	2	0·248	16·7	13	7·100	37·1
Disease	3	0·372	25·0	4	2 185	11·4
Climate	1	0 124	8·3	2	1·093	5·7
Pollution of water	4	0·495	33·4	3	1·638	8·6
Pollution of food	0	0	0	1	0 546	2·9
Vandalism	0	0	0	1	0 546	2·9
Unspecified	1	0·124	8·3	1	0 546	2·9
Total	12	1 487	100·0	35	19·115	100·0

a Actual number of incidents recorded
b Number of incidents per 1 000 tons of production
c Percentage of total number of incidents

From Table IV it may be seen that water pollution and disease are the two major causes of large losses in Group A. In contrast, husbandry and management, and systems failures are responsible for the majority of the smaller incidents in Group B. The total number of incidents resulting in small losses per 1 000 tons of production was much greater than the number of those resulting in large losses.

Table V shows the actual production losses resulting from occurrences of high mortality due to the various causes (data from Group A only). The cause of greatest production loss was water pollution; other causes were relatively unimportant in terms of lost production.

Table VI gives the losses of different sized fish (data from Group B only) due to the various causes and shows that the pattern of losses changes with the size of fish. Systems failure and disease are responsible for most of the losses of small trout, whereas husbandry and management faults are the major causes of mortality of larger fish.

6 Discussion

This preliminary study of the causes of mortality on European trout farms is based upon very small samples, which may be unrepresentative of the many hundreds of trout farms in Europe. Those in Group A may be representative of the type of farm which requires mortality insurance cover, since all the farms included have at least seriously contemplated purchasing such insurance. The farms in Group B may be representative of trout farms in England and Scotland. Of the 16 farms, 8 had purchased insurance of some kind. A larger sample might reveal that trout farmers insuring against mortality are either more careful or professional in their attitude to trout production than others, or that they are more accident prone and thus more conscious of the risks involved. There may also be a greater incentive to insure against larger, newer, or more capital-intensive farms.

The following points emerge from the results:

(*i*) Large insurable losses are less common than small losses which would not be covered by any mortality insurance, but are nonetheless in excess of normally expected mortality. Many of the small incidents do not significantly affect final production, whereas the larger losses may substantially reduce it. Difficulties arise in attempting to compare the costs of large and of small losses, but it seems possible that, for the industry as a whole, the total value of the many small mortalities may be greater than that of the few catastrophes.

(*ii*) The major causes of high mortality differ from the causes of smaller losses. The trout farmer is often conscious of water pollution and disease as potential threats, and indeed these are the most important causes of large losses (58·4% of incidents). However, they account for only a minor proportion of the total number of incidents resulting in mortality. Systems failure and husbandry/management errors result in 65·7% of the smaller incidents (Group B).

(*iii*) The pattern of causes of loss changes through the production cycle, and the number of fish lost decreases as the fish grow.

The risk profile of an individual trout farm closely reflects the quality of managerial decision-making. Thus, strategic decisions relating to site selection, design and production plans, and tactical decisions on day-to-day husbandry practice largely determine susceptibility of the stock to most of the risk categories above. Whereas the risk of nearly all small losses and many large losses can be reduced by improved management, certain large losses (*eg*, theft, malicious damage, some systems failures and water pollution) may be less easily controlled and the financial risks involved in such losses may be reduced by appropriate mortality insurance.

Comprehensive records should enable the existing trout farmer to establish the most common causes of mortality on his farm and take steps to remedy them (Roberts and Shepherd, 1975). Evidence of such practice may also be a consideration in the assessment of insurance premiums since it indicates the extent to which management is aware of the inherent risks on the farm. Accumulation of data on causes of mortality will enable many risks to be eliminated during the planning stage in the development of new farms. Actuarial evidence from insurance claims requiring detailed outside scrutiny of the nature of the incidents will reveal the true causes of trout farm mortality. Accumulation of this data may confirm the causes described in this paper and elsewhere in the literature.

Further investigation of the causes of mortality on Euro-

TABLE V
SUMMARY OF PRODUCTION LOSSES BY CAUSE IN GROUP A

Cause	Number of incidents	Production loss (tons) per 1 000 tons production	Percentage of total losses
Systems failure	1	0·30	0·87
Husbandry/management	2	0·71	2·07
Disease	3	1 49	4·34
Climate	1	2 47	7·20
Pollution of water	4	29·10	84·79
Pollution of food	0	0	0
Vandalism	0	0	0
Unspecified	1	0·25	0·73
Total	12	34·32	100 00

TABLE VI
NUMBERS OF TROUT LOST IN GROUP B ACCORDING TO CAUSE AND SIZE GROUP (PERCENTAGE OF TOTAL FOR EACH SIZE GROUP IN PARENTHESES)

Cause	Weight group of trout lost				
	5 g	5 30 g	30–100 g	100–200 g	200 g
Systems failure	1 681 000 (80·28)	20 000 (10·32)	25 000 (15·84)		1 000 (8 33)
Husbandry/management	12 000 (0·57)	22 800 (11 76)	19 200 (12 17)	68 800 (90 76)	10 000 (83·34)
Disease	200 000 (9·55)	150 000 (77·40)	60 000 (38·02)	6 000 (7 92)	—
Climate	60 000 (2·87)	—	12 600 (7·99)		—
Pollution of water	100 000 (4·78)				—
Pollution of food	40 000 (1 91)	-	—	-	
Vandalism	— —		40 000 (25 35)	—	
Unspecified	1 000 (0 04)	1 000 (0·52)	1 000 (0·63)	1 000 (1·32)	1 000 (8 33)
Total	2 094 000	193 800	157 800	75 800	12 000

pean trout farms should enable risks to be considerably reduced through internal improvements. This will ensure that the mortality insurance now available to the trout farmer continues to be provided at acceptable cost and without exposing the underwriter to excessive financial risk.

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Strategy for Future Development of Aquaculture in Japan

I. Asano

Abstract

Aquaculture plays an important role in Japanese fisheries, producing a total of 0·6 million tons of oysters, scallops and seaweed alone in 1974. Its contribution to the fishing industry is both indirect, through stimulating harvest of trash fish to be used as feed for cultured organisms, and direct, through production to meet the high demand for aquatic foods in Japan.

Considerable success has been obtained recently through culture-based fisheries (*ie*, artificial propagation of juveniles, which are stocked in the natural environment) for Kuruma shrimp (*Penaeus japonicus*), red seabream (*Pagrus major*) and Pacific salmon (*Oncorhynchus*), and development of this form of aquaculture is expected to supercede the 'feeding' type of aquaculture in the future.

It is essential that planning aquaculture development in Japan must be considered with the development of the coastal fisheries economics, and should include, as in the past, support from and involvement of the central and local governments and private enterprise. Recent developments and future activities related to aquaculture research and extension services, and the activities of private enterprise are described. The central government plays an important role in providing supporting services for the aquaculture industry, and it is estimated that the central government invests Yen 100 000 million (US$ 33 million) annually in its comprehensive aquaculture programme.

Planification du développement futur de l'aquaculture au Japon

Résumé

L'aquaculture joue un rôle important dans les pêches japonaises, en 1974, la production d'huitres, coquilles St-Jacques et algues a atteint a elle seule le total de 0,6 million de tonnes. La contribution de l'aquaculture a l'industrie de la pêche est à la fois indirecte, puisqu'elle stimule la récolte de poissons de rebut qui seront utilisés comme aliments

dans les élevages, et directe, puisque la production est destinée à répondre à la forte demande d'aliments d'origine aquatique enregistrée au Japon.

Des succès considérables ont récemment été obtenus grâce aux pêcheries basées sur l'élevage (propagation artificielle de juvéniles, qui sont relâchés dans le milieu naturel) de crevettes Kuruma (*Penaeus japonicus*), de daurade japonaise (*Pagrus major*) et de saumon du Pacifique (*Oncorhynchus*); en se développant, cette forme d'aquaculture devrait dans l'avenir supplanter l'aquaculture du type 'nourrissage'.

Au Japon, il est indispensable que la planification du développement de l'aquaculture soit considérée dans le cadre du développement des économies halieutiques côtières et qu'il soit fait appel, comme dans le passé, au soutien et à la participation du gouvernement central et des autorités locales, ainsi que des entreprises privées. On décrit l'évolution récente et les activités futures des services de recherche et de vulgarisation aquicoles, ainsi que les activités des entreprises privées. Le gouvernement central joue un rôle important en fournissant des services de soutien au secteur de l'aquaculture et l'on estime qu'il investit chaque année Yen 10 milliards (US$ 33 millions) dans l'ensemble du programme d'aquaculture.

Estrategia para el desarrollo futuro de la acuicultura en el Japón
Extracto

La acuicultura desempeña una función importante en las pesquerías japonesas. La sola producción de ostras, vieiras y algas cultivadas fue en 1974 de 0,6 millón de toneladas. La contribución de la acuicultura a la industria pesquera es tanto indirecta como directa, ya que, además de fomentar la captura de morralla para utilizar como pienso para los organismos cultivados, produce parte de los recursos que son necesarios para atender la elevada demanda de alimentos de origen acuático existente en el Japón.

Recientemente han tenido mucho éxito las pesquerías basadas en el cultivo (es decir, la reproducción artificial de formas juveniles y su siembra en el medio ambiente natural) de camaron Kuruma (*Penaeus japonicus*), pargo (*Pagrus major*) y salmon del Pacífico (*Oncorhynchus*), y se espera que esta forma de acuicultura sustituya en el futuro a la acuicultura convencional.

Es esencial que, al planificar el desarrollo de la acuicultura en el Japón, se tenga en cuenta el desarrollo de la economía de las pesquerías costeras y se cuente, igual que en el pasado, con el apoyo y participación de las autoridades centrales y locales y de las empresas privadas. Se describen los últimos progresos y las actividades futuras de la investigación y de los servicios de extensión en el campo de la acuicultura, y las actividades de las empresas privadas. Las autoridades centrales desempeñan una función importante mediante sus servicios de apoyo a la industria acuícola, y se calcula que el gobierno central invierte anualmente Yen 100 000 millones (SFF.UU 33 millones) en el programa acuícola.

1 Direction of development of Japanese fisheries

Fishing is an important industry in Japan which helps to meet more than half of the total animal protein requirement in the country.

Although Japan is the largest fish producer in the world (10·7 million tons in 1973), it cannot meet its own strong demand for fish for human consumption and for the livestock feed manufacturing industry, and has to import more than one million tons of fish annually. Considering fisheries on the global basis, the rate of increase of production from fisheries is higher than that for grains and livestock industries, and the trend to exploit the source of animal protein in fisheries is becoming more and more evident.

As Japan cannot obtain sufficient quantities of imported fish products to fill the gap between demand and supply, it has been trying to exploit new fishing grounds and developing unproved techniques for fishing and processing. Considerable effort has been made to develop aquaculture techniques as well as fishing methods to take advantage of the high productivity of Japanese coastal waters.

2 Role of aquaculture in Japanese fisheries

Aquaculture plays an important role in Japanese fisheries through its increased fishery production. For example, 211·5 thousand tons of oysters (*Crassostrea*), 62·6 thousand tons of scallops (*Pecten*) and 337·7 thousand tons of seaweed were produced by aquaculture (without any feeding) in 1974. New stocks of fish are being artificially created in areas where they have never existed, *eg*, pond smelt (*Osmerus*), landlocked red salmon (*Oncorhynchus nerka*), black rockfish and seabream (*Pagrus*); and fish are being produced through aquaculture in numbers never achieved by the native stocks (*eg*, salmon and prawn).

2.1 *Indirect contribution to fishery production*

Anchovy (*Engraulis japonicus*) and sand eel (*Ammodytes*), caught incidentally in purse seine and trawl fisheries and formerly discarded, are now being used as feed in aquaculture and it is now possible to encourage further investment in these fisheries. Unless there was a market for these species, the production from these fisheries would not be as high as it is now.

2.2 *Adjustment of the imbalance between fishery production and demand*

Today, demand by the Japanese people for 'sashimi' (raw fish) and 'tempura' is more than one million tons and quite constant. As the price of fish used in these traditional dishes is very high, fishing effort on these stocks has been high and has resulted in reduction of their stock sizes. Even though intensive fishery management measures have been introduced their populations have not yet been restored. Short ages that have consequently emerged have been met by both aquaculture and imports.

Aquaculture activities are generally divided into the following categories:

(*i*) *Aquaculture without feeding, eg*, oyster, scallop and seaweed culture.

(*ii*) *Aquaculture with feeding, eg*, yellowtail (*Seriola quinqueradiata*) and red seabream (*Pagrus major*) culture. If sufficient seed of new species can be obtained this type of aquaculture will increase further.

(*iii*) *Culture-based fisheries* ('*saibai-gyogyo*'), *eg*, Kuruma shrimp (*Penaeus japonicus*) and red seabream. In this category, seed is obtained by artificial propagation and juveniles are released to natural fishing grounds after a short rearing period. Production and stocking of high-priced fish has been increasingly undertaken in this fish farming type of aquaculture. As a result, recent production of shrimps in some areas in which stocking has been carried out is increasing.

3 Recent technical innovations

Recently, seed production techniques have developed remarkably and, in future, the 'stocking' type of aquaculture will predominate over the 'feeding' type of aquaculture. With the development of stocking techniques, it will be possible to produce species beyond their natural productivity. In this respect, techniques have been developed for seed production of shrimps, seabream and Pacific salmon (*Oncorhynchus*).

In the 'feeding' type of aquaculture, *eg*, of yellowtail, the combined production of yellowtail from capture fisheries and aquaculture has, in recent years, resulted in the highest recorded catches of this species. Thus, aquaculture is important in Japan because it contributes not only to increasing the income of fishermen, but also to increasing fish production.

However, the feeding type of aquaculture has several disadvantages. Firstly, feed conversion rates are too low

and the loss of animal protein used for feed is too high. Secondly, the productivity of fishing grounds decreases because of the environmental hazards caused by intensive use of marine areas. The former problem should be dealt with as a part of the national food production programme. In this case, we should take into account not only the amount of animal protein to be produced but also the variety of food. A certain amount of production of high-priced fish is always necessary to meet the particular tastes of the Japanese. The latter problem is purely technical and could be solved by fishery scientists. One method of resolving it is to use the stocking type of aquaculture.

As already pointed out, in order to meet the demand for seafood in Japan, a more efficient and proper fish production system should be established. From this point of view, promotion of aquaculture is necessary and the government has been taking the necessary action.

4 Planning of aquaculture development

In Japan, it is essential that planning of aquaculture development must be considered together with the development of the coastal fishery economics. In 1961, an amelioration programme of coastal fisheries was started with a view to utilizing the coastal fishing grounds rationally and efficiently, and to make the fishing industry stable and prosperous. In order to implement this programme, the Japanese archipelago was divided into 42 areas according to their different oceanic environments, ecological situations and the structures of the local society, *etc*. The programme has been sponsored by the central and local governments as well as by local fishermen, and it contains different features for different areas.

The main work has been to: set out fish shelters in a systematic fashion with a view to increasing fish and shellfish production, establish or improve facilities for culture based fisheries, and rationalize the distribution of fish products.

A second amelioration programme started in 1971. At the same time, the Marine Fishery Resources Development and Promotion Law was enacted with a view to promoting aquaculture. Under this law, the Minister of Agriculture and Forestry was to establish a fundamental aquaculture policy every five years. In the basic policy, the Minister designated the species of marine animals and plants for which aquaculture should be promoted, environmental standards, the target production for aquaculture and necessary measures to achieve this target. In accordance with the basic policy, governors of prefectures also designated areas in the waters under their jurisdiction, in which aquaculture should be intensively promoted.

Furthermore, the central government enacted the Coastal Fishing Ground Consolidation and Development Law in 1974 to promote activities which would increase fisheries production in the coastal areas. Under this Law, the central government planned and carried out a programme of consolidating projects.

5 Research institutions

5.1 *National research laboratories*

For research purposes, Japanese coastal areas are divided into six regions with a regional fisheries research laboratory in each. In addition, there are the Freshwater Regional Fisheries Research Laboratories and the Far Seas Fisheries Research Laboratory. The freshwater laboratories have aquaculture departments and conduct basic research. Recently, besides studies related to the promotion of aquaculture, research has also been conducted on ocean pollution and the accumulation of toxins in fish.

Research requiring action on a nation-wide scale is carried out jointly and in co-ordination with all laboratories. One such recent project is 'comprehensive research on the development of grounds for aquaculture in shallow waters'.

5.2 *Prefectural experimental stations*

Every prefecture has at least one fisheries experimental station; there are 82 of these in Japan, including inland water stations. The main task of these stations is to apply research results, obtained at universities and national research laboratories, in the prefectures. They also conduct studies jointly with universities, national laboratories or other prefectural stations.

The government subsidizes these stations in cases where the research is important, and also educates and trains researchers of these stations when they study new subjects, such as fish disease or ocean pollution.

5.3 *Construction of pilot plants*

The central government, in co-operation with the prefectural governments, establishes the bodies which apply the results obtained by the prefectural research experimental stations to commercial-scale operations on an experimental basis.

One of these bodies is the Seto Inland Sea Farming Fisheries Association. This Association, with six stations, is promoting a new type of technology. This is an experiment to increase fishery resources on a gigantic scale through massive artificial seed production and stocking. This technique has already been applied to freshwater fish, such as common carp (*Cyprinus carpio*), ayu (*Plecoglossus altivelis*), and rainbow trout (*Salmo gairdnerii*); and to anadromous salmon. Recently, a start has been made in applying this technique to other species such as Kuruma shrimp and red seabream.

As these efforts proved to be successful, action was initiated in 1973 to establish at least one fish farming centre in each prefecture and 16 centres are now under construction. The central government is subsidizing the construction and providing financial and technical assistance for their operation.

6 Extension services

Neither the programme of aquaculture development by the central government and prefectures nor research activities can be carried out efficiently without the interest and creativity of the fishermen. Thus, the role of the extension officers who instruct the coastal fishermen in new technology and business management of fisheries has grown in importance.

The prefectural governments have some 100 extension centres with 531 fisheries extension officers under the technical and financial assistance of the central government. They are distributed throughout the coastal area of Japan with roughly one officer to three coastal villages. These officers not only provide guidance in technology and

business to fishermen, but they also examine as a whole the present conditions and the future direction of the fishing villages. There are also groups of youths in the coastal fisheries co-operatives studying technology and other promotion activities, and the extension officers serve as good consultants for them.

7 Activities of private enterprise

In order to develop the aquaculture industry, necessary materials and equipment and construction techniques are as important as oceanographical and biological information and techniques. Therefore, private enterprises also promote scientific research in co-operation with the governmental development programme, and have established aquaculture research groups for each special field. The government encourages these activities.

8 Financing

The annual investment by the central government for the comprehensive aquaculture programme amounts to about Yen 100 000 million (US$ 33 million). In addition to this, educational activities, including school education and social education for aquaculture, have been financed by the central government.

Credit for Aquaculture

R. Hamlisch

Abstract

Availability of credit will be a key element in the implementation of future plans for aquaculture development.

Specialized credit schemes should be set up wherever major development is foreseen. This is to ensure both that loan applications are processed by staff with aquaculture experience and that there is no discrimination against the fish farmer, which might be the case where agricultural or capture fisheries financing is the main objective of the scheme.

For large scale, new settlement programmes, governments must take the lead in providing necessary finance, since land has at best only a nominal value as collateral and since there is no risk experience to permit banking institutions to make funds available.

Small scale operators can be expected to experience difficulties in raising credit funds on a continuing basis because of inability to provide collateral, to pay prevailing commercial interest rates, *etc.* Government credit support for this sector should take account, not only of technical improvements of the farms, input provision, and crop financing but also of the most essential social needs to enable the farming family to take its place in society. Satisfying credit needs, in turn, is merely one aspect of development efforts and must be carefully linked to all other phases of small scale aquaculture development.

Experience information from a limited number of aquaculture programmes has given some indication of what to do and what not to do in devising credit schemes for the benefit of the sector. Too few of those countries with ambitious plans for aquaculture development have, as yet, made a serious effort to determine whether existing credit facilities and arrangements will meet the demands to be made of them. Adequate credit support for the sector, therefore, requires a review of national credit facilities in relation to plans for aquaculture development, as well as improvement in existing credit schemes, through application of lessons learnt from schemes that have been in operation for sufficient time to discover their advantages and disadvantages.

Le financement de l'aquaculture

Résumé

La mise en œuvre des plans futurs de développement aquicole sera fonction des crédits disponibles.

Des programmes de crédit spécialisés devraient être élaborés chaque fois que l'on prévoit des développements importants; de la sorte, les demandes de crédit pourraient être traitées par un personnel au courant des questions d'aquaculture; d'autre part, le risque de discrimination à l'encontre du pisciculteur, qui pourrait se produire lorsqu'un programme se propose pour principal objectif le financement de l'agriculture ou des pêcheries.

Pour ce qui est des programmes d'implantation à grande échelle, les gouvernements doivent en prendre l'initiative en fournissant les crédits nécessaires car la terre ne saurait, au mieux, que constituer une garantie nominale et les banques devant dégager des fonds ne sont guère expérimentées en matière de risques.

On peut s'attendre à ce que les petits entrepreneurs cherchant à se procurer des crédits de façon répétée éprouvent des difficultés du fait de leur inaptitude à fournir des garanties à payer les taux d'intérêt en vigueur dans le domaine commercial, etc. L'aide des gouvernements dans ce secteur devrait se proposer non seulement l'amélioration technique des stations, la fourniture d'inputs et le financement des captures mais aussi tenir compte des impératifs sociaux et fondamentaux pour permettre à la famille du pisciculteur de jouer son rôle dans la société. D'ailleurs, faire face aux demandes de crédit ne constitue qu'un aspect des efforts de développement et doit être soigneusement imbriqué à toutes les autres phases du développement aquicole à petite échelle.

L'expérience acquise dans quelques programmes d'aquaculture fait ressortir les obligations et les interdits de l'élaboration de programmes de crédit destinés à ce secteur. Trop peu nombreux sont les pays dotés de plans de développement aquicole ambitieux et qui se soient sérieusement efforcés de déterminer, au cours de la mise en oeuvre desdits plans, si les possibilités et les modalités des crédits existants répondent aux besoins. Toute rationalisation de l'aide au crédit aquicole implique que l'on procède à l'examen des facilités nationales de crédit en matière de développement aquicole planifié ainsi qu'à l'amélioration des programmes de crédit existants compte tenu de l'expérience acquise dans les programmes qui ont fonctionné pendant assez longtemps pour qu'apparaissent leurs avantages et leurs inconvénients.

Créditos para la acuicultura

Extracto

La disponibilidad de creditos será un elemento decisivo para ejecutar los planes futuros de desarrollo de la acuicultura.

Donde se prevea un desarrollo importante de esa industria habran de establecerse esquemas especiales de crédito, con objeto de que las solicitudes de prestamo sean tramitadas por personal con experiencia en acuicultura y se evite toda discriminacion contra el piscicultor, como podria ocurrir cuando el objetivo principal del plan es la financiacion de actividades agricolas o pesquerias de captura.

Cuando se trate de programas a gran escala, de creación de nuevas instalaciones, los gobiernos habrán de tomar la iniciativa en el campo de la financiación, ya que la tierra, a lo sumo, tiene valor nominal como garantia y, no teniendo experiencia sobre los posibles riesgos, las instituciones bancarias no pueden permitirse facilitar fondos.

Cabe esperar que los pequeños productores experimenten dificultades para obtener créditos con carácter continuo, por no poder ofrecer garantias o no poder pagar los tipos normales de interés comercial, etc. El apoyo gubernamental a los créditos para este sector debe tener en cuenta no solo las mejoras técnicas, el suministro de insumos y la financiación de la explotación, sino también las necesidades sociales más imprescindibles, para que la familia del piscicultor pueda ocupar el lugar que le corresponde en la sociedad. La satisfaccion de las necesidades de crédito, por otro lado, no representa más que un aspecto de los esfuerzos de desarrollo y ha de estar estrechamente vinculada con todas las demas fases del desarrollo de la acuicultura a pequeña escala.

La informacion sobre la experiencia adquirida en un número limitado de programas de acuicultura ha proporcionado algunas indicaciones sobre lo que debe y no debe hacerse al proyectar planes de créditos para ese sector. Son demasiado pocos los paises con planes ambiciosos de desarrollo de la acuicultura que hasta el momento han hecho un esfuerzo serio para determinar, durante la ejecución del plan, si los servicios y disposiciones en materia de créditos son suficientes para atender a la demanda. Para que los créditos para ese sector sean suficientes, es necesario revisar los servicios nacionales de credito a la luz de los planes de fomento de la acuicultura, mejorar los programas existentes de crédito aprovechando la experiencia conseguida en planes que hayan funcionado tiempo suficiente para poder apreciar sus ventajas y desventajas.

1 Introduction

Plans for aquaculture development in developing countries have been substantially expanded in recent years because of, among other reasons, world trends in capture fisheries and food economies which have made it necessary to look for new animal protein supplies for human consumption. Realization of these more ambitious aquaculture plans, it is

generally acknowledged, will hinge to a large extent on the availability of finance. Since planned development usually involves creation of new or expansion of relatively young enterprises, prospects for generating adequate funds from within the aquaculture sector must be considered poor. It can be expected, therefore, that credit will have to play a key role in achieving growth targets. There is a dearth of information on the subject, and for this reason there are good grounds to consider some of the issues associated with the provision of credit facilities for aquaculture.

2 The risk element in aquaculture and capture fisheries

A sector's ability to attract finance, and specifically credit funds, depends very much on the evaluation of risk elements by prospective financiers or creditors. The risks commonly experienced in aquaculture operations have been discussed in some detail in the aquaculture literature (Webber, 1973). Occasionally, one also finds in this literature comparisons with risk factors in capture fisheries which are made for the purpose of assessing the relative abilities of the two branches of fish production to raise loan funds.

Compared with capture fisheries, which for the most part exploit common property resources, aquaculture operations in areas where ownership rights are established are less 'mobile' (FAO, 1975). In theory, capture fishermen are able to move, within the technical limitations imposed by the boats and gear they employ, from one fishing area or from one fish stock to another. Where fish stocks located within the operational radius of the equipment are less than fully exploited, and where market conditions, too, are favourable, this mobility of capture fisheries may be taken into account in investment appraisal and assessment of funding possibilities. In other situations, where alternative fishing areas must be considered as fully exploited, the wandering fishermen may 'export' economic difficulties from one area to another, and mobility may be a vice rather than a virtue. Even where the mobility of capture fishermen tends to enhance potential earning power, it may still be a disincentive to credit extension, since collection of evidence for an appraisal of creditworthiness, as well as acceptance of the fishing vessel as chattel mortgage and loan repayment arrangements, may present serious difficulties.

Another factor mentioned in comparisons between aquaculture and capture fisheries relates to the circumstances that, in capture fisheries, production is largely determined by uncontrollable natural forces, while in aquaculture it can be expected to vary with the quantity and quality of inputs (*eg*, artificial feeds and fertilizer) (FAO, 1973).

Capture fishermen are sometimes considered to be at a serious disadvantage in procuring credit assistance because they are unable to furnish acceptable loan collateral. Banks usually prefer, and even insist on, immovable property (real estate and buildings) as security and often refuse in principle to accept a chattel mortgage on a fishing vessel. Even where vessels are acceptable as security, banks may be reluctant to extend a loan on such collateral if there are no safeguards against a transfer abroad of the property title or if the vessel has not been insured. The established aquaculturist usually owns land or other real estate property, which may be of help in obtaining loan funds from a bank. For the new settler, possession of title to the land on which aquaculture operations are to be initiated may be of little or no help in credit procurement, since the land is quite often only of marginal economic value. Also, where aquaculture is promoted by the state, the land may be made available to the settler on a lease basis and banking institutions may refuse to accept the lease contracts as loan collateral.

Aquaculture, it is sometimes said, may be at a disadvantage in certain respects vis-à-vis capture fisheries and agriculture, because it is a relatively new branch of industry. In many countries there are still gaps in knowledge on technical and economic aspects (FAO, 1973) and there may be only a limited number of examples of viable and successful operations from which one could draw yardsticks for appraising project proposals.

Also, because the industry is comparatively new, and because it often still lacks appropriate organizational structures as well as political support, aquaculture in many countries has not been able to obtain for itself certain benefits from the state such as, for instance, production subsidies, which farmers and capture fishermen have come to accept as part of what is 'naturally due' to them.

On balance, however, taking into account all the aforementioned as well as some other factors, it would appear that aquaculture is a less risky economic activity than fishing, primarily because problems associated with locating and controlling the resource (*ie*, fish-finding and fishing in competition with others who have access to the same fishing areas) are avoided.

The individual investor, of course, will appraise risk factors on a situation by-situation basis in addition to consideration on a sub industry basis. Aside from biological risks (fish diseases, parasites, predation, *etc*) and physical risks (poor water quality, storms, heavy rainfalls, *etc*), there is a variety of economic factors he will consider in estimating the soundness of an investment. At the national level, additional factors are taken into account in the determination of the net social benefits which the country may expect from aquaculture development.

3 The place of credit in an aquaculture development programme

Rough estimates have been made of increases in aquaculture production that may occur through expansion of areas under culture, through improvements of existing systems of aquaculture operations, and through the development of new culture techniques. These estimates indicate that the potential may be as much as ten times or more the present level of production (Pillay, 1973). For this reason, one may foresee a very large demand for credit for aquaculture investments notwithstanding technical and other constraints that may hold back investments in some cases as well as government grants and owner capital contributions to project costs which will reduce the need for borrowed funds. Credit facilities, furthermore, will be required to assist established fish farmers in input and in crop financing, and for consumption loans.

Government priorities will decide which operations, and which sector of the population, are to be supported by credit as well as other facilities that are made available for aquaculture operations. The emphasis may be on: (*a*) development of new farms versus assistance to existing farms; (*b*) large-scale commercial versus small-scale or subsistence operations; (*c*) export-oriented operations versus operations for domestic markets; (*d*) one or more of

different types of culture operations, including culture for food production, for improvement of natural stocks, for the production of bait, sport or ornamental fish, etc. (FAO, 1973); (*e*) one or more of different methods of production, including hatchery operations, capture and confinement of young, and raising of the young from eggs obtainable from wild parents (Idyll, 1973).

Aside from, or as an alternative to, financial assistance, government is likely to make available a variety of services. The close to 30 000 aquaculturists of Japan, for example, were reported a few years ago to be benefiting from programmes that included the supply of fry and young invertebrates, disease control, scientific and technological experimental work and extension services which assisted in introducing improved methods, promotion subsidies and administrative guidance (Milne, 1973).

Credit facilities, it must be realized, are just one means of lightening financial burdens. Depending on how far the government wants to go in achieving given policy objectives, the range of possibilities extends from outright grants to concessional credit terms, fiscal relief of some sort, provision of inputs or management expertise, and to sales to the industry on advantageous conditions.

4 The role of government in the provision of aquaculture credit

A general principle that applies to government credit is that it should be extended only if other credit facilities are not in a position to meet the need or are not in a position to meet it to the extent, and as rapidly as, desired under public policy — of the section seeking loan assistance. Government credit and other financial assistance, therefore, has a main role in helping to launch pioneer ventures operations which the private banking system will shun because it lacks a gauge for assessing risks. In contrast, an established industry that is prosperous should have no difficulty in obtaining finance on reasonable terms and should be able to dispense with public credit support.

To cite an example, the Government of the Philippines hopes to use an estimated 500 000 ha of marginal land for aquaculture purposes and for this reason is prepared to provide extensive public assistance, including credit facilities. In Thailand, on the other hand, where the average income of aquaculturists is six times as large as that of farmers and substantially higher also than that of coastal, small-scale fishermen (FAO/UNDP Aquaculture Development and Coordination Programme, 1976), it may be expected that the credit needs of the bulk of the fish farmers will be readily met by existing banking facilities. Even in Thailand, however, the Government may continue to shoulder important burdens in connexion with aquaculture development, since, to ensure the healthy growth of the industry, it will have to finance aquaculture research, training, extension and other infrastructure requirements. In addition, it will incur expenditures for pollution or disease control to protect the fish farmer against developments in areas beyond his control. Finally, if it intends to help the financially weak small-scale operator to survive or if it wants to settle additional areas suitable for aquaculture by transferring capture fishermen from subsistence fisheries, it will have to devise integrated programmes for assistance, an important component of which will be concessional credit.

5 Sources of credit for aquaculture

From the above it might be concluded that government can be expected to take the initiative primarily in financing infrastructure facilities, pioneer ventures, large-scale new development and small-scale operations at the economic margin. These, incidentally, are also the fields which usually are of special interest to international or regional financing institutions which extend credit for agricultural and fisheries development. Other credit, especially for short-term working capital and for consumption needs, is in general made available by other sources, including the established banking system, agricultural estates, and a large variety of other lenders (family members, middlemen, private lenders, suppliers of requisites, *etc*).

The question may be raised whether specialized credit facilities need to be created because existing institutions might tend to ignore the financing needs of aquaculture, since in many cases it is a new industry which has to compete for loans with well established, commercially oriented enterprises. While it is doubtful that the volume and size of aquaculture credit transactions in any country might, within a foreseeable future, reach levels to justify establishment of special investment agencies such as the Fishery Banks which have been set up in a very few countries, a good case can be made for the organization of special aquaculture credit schemes. Only too frequently, development potential is not adequately exploited because of lack of separate arrangements for the examination and processing of aquaculture loan requests. As long as loans for aquaculture purposes are extended under fisheries or agricultural credit schemes, one can expect that aquaculture applications often will not only be given a lower priority but also will not have the benefit of expert appraisal and administration necessary for achievement of the credit support objectives.

Once there is a general consensus on the desirability of setting up separate aquaculture credit arrangements, a decision has to be made on the administrative locus of such facilities, especially where a variety of credit institutions under agricultural, fisheries and co-operative auspices exists. Because of property rights to the 'place of business', the need for making improvements to the land, the character of the inputs used in production, *etc*, aquaculture resembles agriculture a good deal more than it resembles capture fisheries. If this, in general, would tend to favour having an aquaculture credit scheme administered by an agricultural credit institution, the deciding element should be the availability of specialized expertise for servicing the aquaculture loan scheme. In some countries, loan schemes for certain marine aquaculture operations have been administered by agencies which are also responsible for credit for capture fisheries operations. In the long run, it would seem to be preferable, to ensure the most economic use of expertise, to bring all credit operations for aquaculture under one roof.

Where aquaculture is only one of the components of integrated rural development (IRD), aquaculture credit must be considered a part of the entire financing package for implementation of the IRD programme, since setting up a separate fund for aquaculture development would be inconsistent with the basic philosophy of integrated development.

Since no systematic survey has been made in this field, little is known of the identity of the agencies which administer credit schemes for aquaculture in different countries of

the world. In Japan, the following institutions have some share in the provision of credit to fish farmers (Japan Fisheries Association, 1975): (*a*) The Fisherman's Mutual Relief Fund (Gyogyo Kyosai Kikin); (*b*) Central Union of Fishery Credit Guarantee Corp. (Gyogyo Shinokikin Chuokai); (*c*) National Federation of Fisheries Mutual Relief Association (Zenkoku Gyogyo Kyosai Kumiai Rengokai); (*d*) National Fisheries Cooperatives Mutual Relief Association (Zenkoku Suisangyo Kyodo Kumiai Kyosai kai); (*e*) The Agriculture, Forestry and Fisheries Finance Corp. (Norin Gyogyo Kinyukoko); (*f*) The Central Cooperative Bank for Agriculture and Forestry (Norin Chuo Kinko).

While particulars on the nature and scope of lending operations of the above institutions are not at hand, the list indicates that four of them (the first four) are concerned exclusively with the fisheries sector, whereas the remaining two are banking organizations serving all branches of agriculture, forestry and fisheries. In Japan, the fisheries industry, by virtue of its size, has more of an identity of its own than it has anywhere else, which may account for a close association of aquaculture with capture fisheries operations.

Many of the financing institutions active in the distribu tion of credit to aquaculture are either directly or indirectly controlled by the state, which owns all or a part of their capital. Financial resources for aquaculture development of these institutions have, in some instances, been supplemented by credits from international and regional banks. The World Bank, for example, has financed two sizeable programmes in the Philippines (one administered through the Development Bank of the Philippines, the other through the Central Bank, with the Rural Banks system being used as a 'retail distribution' channel) which had important aquaculture components (FAO/IBRD Cooperative Programme, 1972).

The financing of large scale aquaculture development schemes might be undertaken by institutions experienced in backing investment projects of similar size in other branches of industry, such as specialized development or investment banks (Pillay, 1977). Agricultural or fishery banks may be best suited for channelling credit to existing enterprises in the private sector, while co-operative banks may be able to provide similar services for enterprises organized along co-operative lines. The average commercial bank ordinarily confines itself to providing credit for low risk, short-term operations such as the marketing of higher-value export products. Other institutions which sometimes have a role in the distribution of credit to fish farmers are public bodies concerned with industrial, agricultural or fisheries development, and commodity boards which may process and market aquaculture products. These institutions may be used for channelling credit to producers of fish destined for export or for the processing of products (Pillay, 1976).

Not only the character of the loan but also the size of the loan may have a bearing on the channel used for the distribution of funds. In some countries, therefore, credit to large-scale enterprises is distributed through one given channel, while credit to small-scale operators is arranged through another channel. This is the case, for instance, in the Philippines where the Development Bank of the Philip pines extends credit to aquaculturists farming more than 50 ha, while the Rural Bank system attends to the needs of operators with smaller holdings (FAO/IBRD Cooperative Programme, 1972). For effective servicing of the small-scale sector, a net of branch banks is needed which is capable of maintaining local contacts for the determination of credit needs and the supervision of loans. With over 600 branches, the Philippines Rural Banks system is best suited to provide such services.

Allocating loan funds through 'estates' has been consid ered as a possible alternative for distribution of loans to small operators (FAO/IBRD Cooperative Programme, 1972). The idea has appeal because it might ensure better management of the holding and might facilitate supervision of the loans. One estate-like operation, to cite an example, was initiated in the Philippines (Parker, 1974) a few years ago under the auspices of a private company, the object being the commercial farming of red algae (*Eucheuma*). The local operation involved very little overhead expense, no out-of-pocket labour costs since only family labour was employed, and virtually no transportation costs. In order to further reduce the farmer's initial expenditures, the spon soring expatriate company had established a policy of loaning nets without interest or collateral for as long as the farmers used them for red algae cultivation purposes. To get the programme underway, the company had undertaken a cultivation research and farmer training programme, set up a pilot farm, and had provided assistance in site selection for individual holdings and in the promotion of efficient cultivation techniques. In addition, the company had agreed to buy the entire red algae production of the families participating in the project.

The 'estates' idea is not always very popular at the grass roots level, because the farmer may feel he is being down graded to the position of an employee. Moreover, where private expatriate firms are involved, there may be appre hensions about a return to colonialist conditions. Still, the availability of management, training, marketing and other assistance may help to overcome these apprehensions.

6 Credit for launching an aquaculture development scheme

What should be done to create an efficient credit system for aquaculture development may be most appropriately dis cussed by the type of needs to be filled. Arrangements for the provision of investment capital, thus, will differ from those for loans for working capital or for consumption loans. Even within these categories, requirements may differ substantially according to size and type of operation, and stage of development of the industry.

The initial capital outlay for a fish farming operation may vary from a minimum amount where existing water areas such as village ponds and multi-purpose community owned water bodies are used, to substantial sums where expenditures for removal of trees, levelling of grounds and construction of water supply and drainage canals as well as water gates, are involved. If a large undeveloped area (*eg*, swampland) is to be transformed into fish farms, government may have to underwrite a large share of the original cost of the project by provision of grants or concessional credits. Potential settlers are not only likely to lack the needed investment funds but also may not be willing to move to an area that heretofore has been wasteland without receipt of incentives which may involve the expenditure of public funds. In addition to contributing to capital cost,

credit programmes for the new fish farmer must take account of working capital and consumption expenditure needs for a long enough period until the farms become productive. The necessary provisions can be made either by including relevant amounts in the original funding or by facilitating (through guarantees, interest support, *etc.*) credits by banking institutions made available at a later stage when the project becomes operational.

An essential condition for launching a larger-scale development programme is the conduct of a comprehensive and thorough feasibility study. This study has to cover human resources and environmental constraints that may affect the implementation of an otherwise quite promising programme, in addition to biological, technological and economic factors.

Sometimes it is quite difficult at the feasibility stage to envisage the kinds of obstacles that may be encountered in implementation. A fish farming development project prepared for World Bank financing a few years ago had the objective of raising national fish production through the construction of new, and the improvement of existing, fish ponds in a sparsely settled area of a country in southeast Asia (FAO/IBRD Cooperative Programme, 1972). During the preliminary study, components of the proposed project were found feasible. Eventually, however, only the improvement project involving the enlargement, strengthening, and lengthening of dikes, excavation of canals, levelling of pond bottoms, *etc.* was implemented. The construction part of the project proposal, which foresaw the establishment of 200 ha fish farming estates, was shelved among other reasons because of: (*a*) lack of management staff, (*b*) social factors— the new settlers would have been of a faith different from that of the prior settlers, (*c*) ecological reasons the removal of tree stumps might have had a serious impact on the environment (flooding), and (*d*) possible land-use competition- there was some evidence that the population was deriving an income from the sale of firewood taken from the area on which the farms were to be constructed.

Almost as basic a requirement for the success of any aquaculture credit scheme as careful feasibility study is the integration of loan with other development support operations. Efforts must be made to co-ordinate credit with supply, marketing extension and other services, especially insofar as facilities for the small-scale sector are concerned, where a fully integrated approach is essential for the achievement of development aims. Also, because aquaculture is a relatively new industry, loan supervision to ensure that credits are used for the purposes intended and in the most efficient manner is even more important than in other industries.

Another essential requirement for the successful operation of a credit scheme — for that matter for the implementation of any major aquaculture development programme — is the availability of appropriate infrastructure facilities. In many instances, availability of adequate and high-quality fish seed has been a basic requisite for aquaculture development. Not surprisingly, therefore, shortages of seed have been identified as being among the principal constraints to the expansion and intensification of aquaculture in the Asian region (FAO/UNDP Aquaculture Development and Coordination Programme, 1976). While in some countries private companies are playing a major role in the production and distribution of seed, in the majority of instances it may be up to government to remove deficiencies in seed supplies if aquaculture development is to be accelerated.

One word of caution may be given, however, on how far government should go in creating facilities and incentives to stimulate development. While government provision at below-cost prices of seed supplies and the making of other substantial concessions to producers may be fully justified by the order of priority which aquaculture has been given in the national plan of a country, incentive schemes should never be as comprehensive and liberal as to remove the entire burden of risk-bearing from the producer. Unless the beneficiary of an aquaculture development programme has a stake in the venture by virtue of his own contribution to costs, he may not be sufficiently motivated to help make it succeed. In the United Kingdom some years ago, the government insisted, for this reason, when the question of financing basic research and development work for marine aquaculture first arose, that enterprises potentially interested in entering the field make financial contributions to these activities. In a developing country, such pre investment work is more likely to be undertaken with public funds; even there, however, the fish farmer should be expected to make at least a modest investment in the construction of his farm.

By fixing the shares of the total investment cost which borrowers must cover from their own resources, government is able to discriminate between different classes of loan recipients or types of projects. In some instances, therefore, operators farming larger areas are required to make a larger contribution to capital cost than smaller-scale farmers, making it relatively easier for the latter to qualify as beneficiaries of the loan scheme.

Since the main capital investment in aquaculture is the cost of installations (FAO, 1973), the farming of village ponds and multi-purpose community-owned water bodies requires little initial capital. The experts, however, conclude that there is little known as yet on the costs and benefits of such operations beyond the fact that they may present serious difficulties in regard to rational input use and business management. For this reason, governments may be hesitant to place too much emphasis in their aquaculture credit programmes on meeting the needs of operators of such facilities, notwithstanding the large number of people that might be assisted with relatively modest expenditures. Even where the major objective of programmes is to help the small-scale or the subsistence operator, it may be better to limit credit extension to operators that have been proved to be economic, no matter if this might increase the size of the individual loan and, conversely, decrease the total number of operators that can be assisted by a scheme. Decision-making should be related to the number of operators who are likely to reach the stage of economic independence rather than to the total number of people assisted, unless a scheme has no other than welfare objectives.

7 Credit for small-scale aquaculture operations

The established aquaculturist may have several reasons for seeking credit assistance for his farm. Funds may be necessary for improvements in his installations and facilities to prevent deterioration or to raise the efficiency of operations, for the purchase of inputs such as seed and fertilizer, for

working capital purposes in advance of the receipt of proceeds from the sale of crops, *etc.*

The successful large-scale operators may not find it very difficult to secure whatever loan funds he wants to apply for in order to increase the profitability of his farm or to improve the management of the capital at his disposal. He will not lack collateral and his commercial and financial record usually will suffice to support his application for credit extension from a commercial banking institution.

The small-scale operator, in contrast, will be in a very different position. He will be handicapped in a number of ways. He may lack acceptable collateral, the loan interest rates may be too high for him, there may not be any banks from which he might be able to borrow in his vicinity, and credit institutions may not be able to obtain any knowledge on his business operations or his personal record; he, in turn, may be ignorant of existing facilities to which he could have recourse to meet his credit needs. Any of these factors, and most likely several of them, may explain why the small-scale operator may experience difficulties in raising loan funds and to reach the stage for independent economic growth of his business.

To some extent, ability to secure credit assistance de pends on the purposes for which the funds are requested. If the object is to obtain funds, for example, for shrimp export operations, even the small scale farmer may not have any problems in approaching regular banking channels. Many commercial banks, thus, are said to see in crop financing an excellent way of employing their funds on a short-term basis (FAO, 1973a). Expansion of lending of this type, it has been pointed out, has been held back by lack of crop insurance programmes (FAO/IBRD Cooperative Programme, 1972).

Credits for the acquisition of inputs may be made available under revolving fund arrangements, with the original allocation of finance coming from budgetary sources. Another potential source of funds for these purposes may be the large company which, with the already mentioned 'estate'-type of operation, may undertake to finance inputs in addition to purchasing the small farmer's harvest, and to processing and marketing the crop.

A fairly general feature of schemes facilitating the acquisition of inputs is that the borrowers are not provided with cash but with the actual equipment they want to buy. The rationale for this procedure is two-fold; on the one hand, the lending agency, which has a certain expertise in the field, helps decide what and how much are needed; on the other hand, there is no possibility that beneficiaries of the scheme use cash funds made available to them under the scheme for purposes other than those for which the scheme is operated. Even then, however, the aims of loan assistance may still be frustrated if the beneficiaries of a scheme which is to facilitate the acquisition, for example, of feed, harvesting gear, fertilizer, *etc*, sell the supplies which they have ob tained as a result of this assistance in the open market, and there is therefore need for close supervision in all credit operations.

In some rural societies, small-scale farmers have been wont to use short-term cash credits extended for production purposes, for personal consumption uses including housing, socio-religious ceremonies, and to meet family financial commitments such as expenses for school fees, hospital bills, *etc*. While a comprehensive credit programme must ensure that the more important personal needs of the producer and his family are not ignored, in some societies the value of improving the quality of one's assets, instead of merely adding to them, has not yet been fully recognized (FAO, 1973a). Where this is the case, every effort should be made to make fish farmers realize that application of loan proceeds for the purchase of improved tools of production (better seed, feeds, *etc*) rather than for expenditures on non-essential consumption goods will, in the longer run, enable them to obtain disproportionately greater satisfactions.

Inability to produce collateral acceptable to the lending institutions has in many cases prevented small-scale operators from deriving full benefits from credit schemes.

Provision of collateral in small-scale operations is reported to be a problem for aquaculture (South China Sea Fisheries Development and Coordinating Programme, *et al*, 1974) as much as for capture fisheries. While real estate owned by the fish farmer is generally accepted as security, banks may insist that the loan applicant provide evidence that he has full title to it or, if he cannot produce a document in evidence of his possession of title, other proof that no 'sham' ownership is involved (*ie*, they may ask the owner to provide evidence, for instance, that the property has been declared by him for tax purposes for a given number of years and that he and the preceding holders had been in continuous and uninterrupted possession for a given length of time) (FAO/IBRD Cooperative Programme, 1972). As already indicated, farm land is often of little importance as collateral because of the low valuation placed on it by the banks.

Where fish farmers are operating on land leased from government, extension of credit facilities may be hampered by difficulties in obtaining bank acceptance of the leases as security. In the Philippines a few years ago, the Development Bank (DBP) was not prepared to accept a ten-year lease as collateral but indicated that it would consider a 25-year lease, renewable for another 25 years if the lessees had complied with all lease obligations, as tantamount to full ownership (FAO/IBRD Cooperative Programme, 1972).

Questions relating to land tenure and ownership of water bodies were reported to have been detrimental to a wider use of credit facilities for aquaculture operations in a number of the countries of the Asia and Far East Region (FAO/UNDP Aquaculture Development and Coordina tion Programme, 1976). To overcome such obstacles and to facilitate credit operations, national banks in Indonesia indicated that they were ready to accept, in lieu of collateral security, carefully prepared feasibility studies providing evidence of good prospects of success. In Nepal, the Government announced its readiness to guarantee loans ex tended to recent fishery graduates who entered the industry in order to encourage newcomers to take up fish farming.

Credit costs, too, have been mentioned as a major obstacle to expansion of credit for aquaculture (Pillay, 1977), especially for small-scale operations. In Asia and the Far East, therefore, where credit facilities were available throughout the region, it was thought that credit costs in many cases were prohibitive for a majority of potential loan applicants.

The suggestion has been made that agencies extending credit to aquaculture should charge a concessional rate of interest during the initial stages of development of the industry (Pillay, 1977). Concessional rates of interest, for a set period of time, may be defended on the ground that they

may serve as an incentive to induce borrowers to take out loans for ventures that merit priority support, that the lower costs may be necessary for the critical initial period of operations, or that they may help the entrepreneur to take full advantage of favourable opportunities in a given situation. In principle, interest rates on loans to fish farmers should not differ from those applicable to loans for other sectors of the economy which are given the same order of priority in economic and social planning. Within the sector, of course, distinctions may be made between different types of operations (*eg*, export versus domestic consumption-oriented and classes of borrowers (large-scale versus small-scale operators), again in line with the priority criteria laid down in the economic and social plan. Care has to be exercised that the social objectives of support policies are not lost sight of by, for example, giving large-scale operators the opportunity to borrow at below-market rates from government institutions and banks, while leaving marginal operators at the mercy of private money lenders who charge usurious rates.

Even if the cost of the loan to the individual borrower through a concession on the interest rate has not been intentionally lowered, there are ways and means of keeping the overall cost of a loan programme down in order to increase the number of potential beneficiaries. One way in which savings may be made in the administration of credit schemes assisting fish farmers who are geographically dispersed over a wide area, is to enlist the collaboration of local agencies (*eg*, field personnel of the administrative services concerned with agriculture or fisheries, bank branch offices) and institutions (*eg*, co-operatives) in appraisal and supervision activities.

Another way of achieving savings is through improvements in the management of schemes. Lack of efficiency (or cumbersome procedures) in administration may not only prevent the lending institutions from realizing savings that could be used to expand the credit programme but also may adversely affect the inclination of would be borrowers to avail themselves of the facilities (FAO/IBRD Cooperative Programme, 1972). In one instance, it was reported that, under centralized approval procedures for aquaculture loans, it took up to three months to process a loan application. Since the fish farmers had to have on deposit the share of project costs for which they were responsible while the loan application was being processed, many withdrew their money because they did not want to wait until approval was obtained. Administrators of loan schemes for small scale operators, therefore, would be well advised to make every effort to eliminate bureaucratic formalities that are not absolutely essential and, in general, to see to it that loan processing procedures are speeded up.

There is ample evidence that, in the small-scale sector, potential beneficiaries of loan and other support schemes often fail to take advantage of existing opportunities of obtaining funds. This may be because the agency that administers the programme has neglected to publicize the services it has to offer (FAO/IBRD Cooperative Programme, 1972). Sometimes the producer/potential borrower is too mistrustful of the bureaucratic machinery to investigate opportunities for benefiting from the scheme. In the case of World Bank loan funds which were to be distributed through the Rural Banks system in the Philippines, a disappointing disbursement record was explained, among other reasons, by lack of promotional efforts on the part of the Rural Banks in publicizing the availability of the new credits for small fishermen. This failure to publicize the availability of these credit schemes may have had something to do with relatively low returns on aquaculture credits and the existence of reportedly more profitable outlets for the Banks' loan funds.

8 Features essential for the success of aquaculture credit schemes

In addition to proper consideration of the ability of beneficiaries to take advantage of a credit scheme (*ie*, to raise necessary collateral, pay stipulated interest rates, *etc*), and for co-ordination of credit with other assistance, there are a few more general conditions which a credit scheme must satisfy to stand a reasonable chance of working successfully.

Prospects of success may hinge far less on the overall total of loan funds for distribution than on the availability of the right amount, at the right time, through the right channel, to the intended borrower.

The object of credit assistance may easily be frustrated if the loan funds extended are below the amount the borrower needs and has applied for (Pillay, 1977). There are several reasons for this shortfall in the loan sum: (*a*) the magnitude of the borrower's credit needs may have been underestimated in the feasibility study; (*b*) working capital requirements for a specified period after the project becomes operational may have been ignored in drawing up the credit application (in some countries, long-term loans for aquaculture almost routinely include a line for annual production expenses); (*c*) there may be limitations on the ability of lending agencies to extend funds which, in turn, may reflect the small size of the capital resources of the lending institution, or may result from statutory lending limits applicable to certain types of banks; in addition, various banking institutions may have specific restrictions with respect to the extension of certain types of loans, *eg*, for fish farms of given sizes.

To cite an example in the Philippines, an amount of US$ 1·9 million destined for fish pond development, which was part of a sizeable World Bank loan in 1969, was to be disbursed by the Central Bank of the Philippines through selected banks of the Rural Banks system (FAO/IBRD Cooperative Programme, 1972). According to statutory restrictions, Rural Bank loans to a single borrower could not exceed 15% of the Bank's combined paid-in capital and reserves which, for the average Bank, was about P.Ps. 500 000. The maximum loan the average Rural Bank, therefore, would have been able to make was P.Ps. 75 000, which was considered not quite sufficient for the construction of a 25 ha farm, the minimum size operation that was to be assisted by the scheme.

Restrictions were in force also on loans to aquaculture enterprises. A Rural Bank, thus, could not finance a fish farm larger than 50 ha in size or extend credit to merchants and rural industries or enterprises with less than P.Ps. 25 000 capital investment.

The legal maximum limits of lending to one borrower, it was thought, had the effect that only a few of the largest Rural Banks were in a position to grant a loan satisfying the credit requirements for the construction of farms of a size which the World Bank loan was intended to finance.

Timing decisions are of importance where not only loan

disbursement but also loan repayment is concerned. The money must be available for the borrower when he has to make his input purchases or arrangements for the shipment of his crop; the repayment instalments should be scheduled to ensure remittance when the sales proceeds are likely to be obtained.

The advantages of using local channels for the administration of aquaculture credit schemes has already been discussed. As in any kind of credit scheme, geographic and close acquaintanceship between credit agent and borrower are invaluable assets in administration.

Although it may be true that the development of aquaculture credit facilities has been retarded at times by failure to pay sufficient attention to one or more of the above factors, the relatively slow growth of such facilities on a global basis may have other roots. In the main, it is suggested that this slow growth reflects a lag in technical, management and economic expertise on aquaculture operations, which has held back the development of the industry in some developing regions. Country reports from the Asia and Far East Region on aquaculture development thus, without exception, refer to problems associated with introduction of suitable designs and construction methods for ponds, lack of knowledge and experience in modern culture techniques, lack of availability of seed (considered by some as the most important constraint to expansion), lack of competent management and of other expert staff to carry out project feasibility and analysis work (South China Sea Fisheries Development and Coordinating Programme, *et al*, 1974). Not all of the countries in this region, however, are handicapped in equal measure. The specialists processing aquaculture loans in the Philippines, for instance, are considered highly qualified (FAO/IBRD Cooperative Programme, 1972). At the same time, though, it has been felt that the Rural Banks system in that country might have been able to handle a substantially larger number of loans if additional fishery technicians had been available to assist in the evaluation of loan applications.

9 Conclusions

The gathering momentum of aquaculture development efforts requires that no time be lost in adapting institutional arrangements to give adequate support to such development. With funding a main constraint in most countries of the world, the emphasis must be on creating, expanding, or strengthening aquaculture credit schemes that meet the industry's requirements for investment capital, input purchase, crop financing and essential consumption expenditures of the operator.

Before programmes to effect such improvements can be launched, it will be necessary to identify the specific needs of the countries concerned, by studying existing aquaculture credit facilities in relation to present and prospective plans for development. As more and more of the developing countries are taking steps, within the framework of Regional Workshops organized under the FAO/UNDP Aquaculture Development and Coordination Programme, to outline their plans for aquaculture development, and as supplementary information is being assembled on credit facilities available for aquaculture support, a data base for the proposed exercise is being created. By using this statistical material, an experienced credit operations specialist, working in close collaboration with fish farming experts, should not find it too difficult to draw up proposals for improved facilities and procedures in aquaculture credit administration.

It is suggested, therefore, that this Conference consider the desirability of reviewing national aquaculture credit schemes to determine their adequacy in the light of sectoral development plans, and that it further consider ways and means of organizing the study (including funding, necessary expertise, and duration of research).

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Research and Extension Services for Aquaculture Development

T. V. R. Pillay

Abstract

Aquaculture is a relatively new science which has, in its early stages, been heavily oriented to biological investigations. Production practices have evolved through trial and error, and recent researches have helped in understanding the scientific basis of some of the successful practices. Expansion of aquaculture in the future is expected to be based on transfer of technology, improvement of existing practices, and the development of new technologies

Directed research at a level appropriate for solving the problems encountered in production programmes has to be carried out to support aquaculture development. Such research has necessarily to be multidisciplinary and systems oriented. The facilities required for experimental and pilot scale studies make research of this nature relatively expensive. Although both agriculture and animal husbandry are based on a limited number of species, aquaculture has, for various reasons, to be based on a much larger number of species and consequently calls for much greater

research effort. The development of appropriate technology for the culture of even a small number of species requires more effort and resources than most existing institutions can now afford.

A wide spectrum of inter-related studies is required to develop an aquaculture system or to effect improvements in the existing systems. Recent assessments of current research and future needs on both national and international bases have underlined the need to channel diverse efforts into co ordinated programmes.

A Working Group of the Technical Advisory Committee (TAC) of the Consultative Group on International Agricultural Research and later a Sub Committee appointed by TAC reviewed research needs in developing countries and proposed the organization of co ordinated regional networks, consisting of regional research centres closely linked to selected national centres for research and training purposes. Regional workshops organized by the FAO/UNDP Aquaculture Development and Coordination Programme in Africa, Asia and Latin America considered such networks essential for the implementation of the ten year aquaculture development plans prepared by the participating countries.

Well organized extension services are of crucial importance in aquaculture development, particularly in small scale rural programmes. Extension work may be at two levels, one for the transfer of technology to field technicians and the other to farmers. The technical competence and personal qualities of extension personnel are of special importance in effective extension work. Organizational and institutional support for extension work are also of equal importance. Financial assistance and provision of credit to aquaculturists should be linked to extension services to enable proper utilization of aid for improved farming. Suitable audio-visual aids and ready access to a well organized information system are other important requirements for effective extension activities.

The regional network of research centres recommended by expert groups should be established through co operative efforts of funding agencies interested in aquaculture. Governments should give appropriate priority to organization of research and extension services in development plans. The co operation of industry and academic institutions should also be obtained to facilitate the implementation of research programmes.

Recherche et services de vulgarisation en matière de développement aquicole

Résumé

L'aquaculture est une science relativement récente qui, au départ, était largement orientée vers les recherches biologiques. La production a été pratiquée de façon empirique et le fondement scientifique de certaines pratiques couronnées de succès a été mis en évidence a la suite des recherches récentes. L'expansion ultérieure de l'aquaculture devrait se fonder sur les transferts de techniques, l'amélioration des pratiques existantes et l'élaboration de techniques nouvelles.

Les recherches dirigées, à un niveau propre à résoudre les problèmes que posent les programmes de production, doivent être effectuées en appui au développement de l'aquaculture. Ces recherches doivent nécessairement être multidisciplinaires et systématiques. Les installations requises pour réaliser des recherches expérimentales et pilotes rendent relativement onéreuses les recherches de cette nature. Alors que l'agriculture et l'élevage portent sur peu d'espèces, l'aquaculture doit, pour maintes raisons, porter sur un nombre d'espèces beaucoup plus vaste et demande donc un effort de recherche beaucoup plus considérable. L'élaboration de techniques appropriées à l'élevage d'un nombre même restreint d'espèces demande plus d'effort et de ressources que ne peuvent en mobiliser les institutions existant à l'heure actuelle.

Pour mettre au point un système aquicole ou améliorer les systèmes existants, il faut une vaste gamme d'études liées entre elles. Les évaluations récentes des recherches en cours et des besoins ultérieurs, tant sur le plan national qu'international, fait reconnaître qu'il était nécessaire de regrouper en programmes coordonnés des efforts qui se caractérisent par leur diversité. Un Groupe de travail du Comité consultatif technique (CCT) du Groupe consultatif de la recherche agricole internationale, puis un Sous-Comité créé par le CCT, ont examiné les besoins des pays en développement en matière de recherche et proposé l'organisation de réseaux régionaux coordonnés, composés de centres de recherche régionaux étroitement liés à des centres nationaux choisis aux fins de la recherche et de la formation. Des stages régionaux, organisés dans le cadre du Programme PNUD/FAO de développement et de coordination de l'aquaculture en Afrique, en Asie et en Amérique latine ont jugé essentielle l'existence de tels réseaux aux fins de la mise en oeuvre des plans décennaux de développement aquicole préparés par les pays participants.

L'existence de services de vulgarisation bien organisés est de la plus haute importance pour le développement de l'aquaculture, notamment en matière de programmes ruraux à petite échelle. La vulgarisation peut s'exercer sous les deux formes du transfert de techniques soit à des techniciens extérieurs soit à des pisciculteurs. La compétence technique et les qualités personnelles des vulgarisateurs revêtent une importance particulière dans l'efficacité des activités de vulgarisation. L'aide organisationnelle et institutionnelle aux travaux de vulgarisation est tout aussi importante. L'assistance financière et la fourniture de crédits aux aquaculteurs devraient être liées à des services de vulgarisation, afin que l'aide à l'amélioration des pratiques piscicoles soit utilisée au mieux. Autres aspects importants de l'efficacité des activités de vulgarisation: un matériel audio-visuel approprié et la facilité d'accès à un système d'information bien organisé.

La mise sur pied du réseau régional de centres de recherche recommandée par les groupes d'experts devrait se faire grâce aux efforts conjoints d'agences donatrices intéressées en aquaculture. La planification du développement, notamment au niveau de l'organisation de la recherche et des services de vulgarisation, devrait recevoir de la part des gouvernements la priorité qu'il convient. Pour faciliter la réalisation des programmes de recherche, la collaboration de l'industrie et des institutions académiques est à rechercher.

Investigación y servicios de extensión para el desarrollo de la acuicultura

Extracto

La acuicultura es una ciencia relativamente nueva que, en sus primeras fases, se ha orientado predominantemente hacia las investigaciones biológicas. Los sistemas de producción utilizados son el resultado de una serie de ensayos y errores, y las investigaciones hechas recientemente han ayudado a comprender la base científica de algunos de los sistemas empleados fructíferamente. Se espera que la expansión de la acuicultura en el futuro se base en la transferencia de tecnología, la mejora de los sistemas actuales y el desarrollo de nuevas tecnologías.

Para sostener el desarrollo de la acuicultura es necesario realizar investigaciones directas a un nivel adecuado para resolver los problemas que se encuentran en los programas de producción. Una investigación de ese tipo ha de ser por necesidad multidisciplinal y tener una orientación sistemática. Las instalaciones necesarias para hacer estudios experimentales y piloto hacen que esas investigaciones sean relativamente costosas. Mientras la agricultura y la ganadería se basan en un número limitado de especies, la acuicultura, por diversas razones, ha de basarse en un número mucho mayor de especies y, por tanto, exige un esfuerzo de investigación mucho mayor. La preparación de tecnología adecuada para el cultivo aunque sólo sea de un pequeño número de especies exige más esfuerzos y recursos de los que la mayor parte de las instituciones actualmente existentes pueden permitirse.

Para preparar un sistema de acuicultura o introducir mejoras en los sistemas existentes es necesaria una vasta gama de estudios interrelacionados. Las evaluaciones hechas recientemente de las necesidades actuales y futuras de investigación en el plano nacional e internacional han puesto de relieve la necesidad de canalizar los diversos esfuerzos hacia programas coordinados.

Un Grupo de Trabajo del Comité Asesor Técnico (CAT) del Grupo Consultivo sobre Investigación Agrícola Internacional, y posteriormente un Subcomité designado por el CAT, han examinado las necesidades de investigación de los países en desarrollo y han propuesto que se organicen redes regionales coordinadas, compuestas por centros regionales de investigación estrechamente vinculados con algunos centros nacionales para todo lo relativo a investigación y capacitación. Los Seminarios Regionales organizados por el Programa FAO/PNUD de Desarrollo y Coordinación de la Acuicultura en Africa, Asia y America Latina han considerado que esas redes son esenciales para la ejecución de los planes decenales de desarrollo de la acuicultura preparados por los países participantes.

Para el desarrollo de la acuicultura, especialmente si se desea integrarla en programas rurales a pequeña escala, es crucial disponer de servicios de extensión bien organizados. Los trabajos de extensión pueden realizarse a dos niveles: transferencia de tecnología a los expertos que trabajan sobre el terreno y a los agricultores. Un elemento especialmente importante para que los trabajos de extensión sean eficaces es la competencia técnica y las cualidades personales de los funcionarios de extensión. Igualmente importante es el apoyo organizativo e institucional. Para que sea posible aprovechar adecuadamente la ayuda destinada a mejorar la explotación, es necesario que a los servicios de extensión acompañen servicios de asistencia financiera y créditos a los acuicultores. Otro elemento importante para que las actividades de extensión sean eficaces es la disponibilidad de medios audiovisuales adecuados y el acceso a un sistema de información bien organizado.

La red regional de centros de investigación recomendada por los grupos de expertos deberá establecerse con la cooperación de los organismos financiadores interesados en acuicultura. En sus proyectos de desarrollo, los gobiernos deberán dar la prioridad necesaria a la organización de servicios de investigación y extensión. Es indispensable conseguir también la cooperación de la industria y de las instituciones académicas para facilitar la realización de dichos programas de investigación.

1 Introduction

Aquaculture is not less than 2 500 years old, but scientific research in aquaculture is not much more than 60 years old. This is not surprising. The much older practice of agriculture began 8 000–10 000 years ago but agricultural research started no earlier than some 160 years ago. The

analogy rests there because aquaculture research has to go a long way to reach the level of agricultural research even a century ago. It appears to have originated as part of fish or fishery biological studies and continues to be heavily oriented to biological investigations. Individual researches on the life history and behaviour of cultivable aquatic organisms still form a good part of aquaculture research.

With or without research support, aquaculture has developed into a significant food production industry in some countries, particularly those of Asia and the Far East. Largely, through trial and error, certain systems of culture have evolved and recent research has helped understanding of the scientific basis of many of these practices, enabling improvements to be effected in the techniques. Transfer of these existing technologies is conceived as the first step in the expansion or introduction of aquaculture, particularly in the developing countries. This will undoubtedly involve testing and modifications of techniques to suit local requirements. Research so far carried out in aquaculture has demonstrated that existing technologies can be greatly improved, enabling intensification of culture operations and consequent increases in yields and profitability. The need for developing new technologies and new systems of culture based on new species to meet domestic or export market requirements is widely recognized; and scientific research is obviously required for this purpose as well. Thus, any form of aquaculture development needs scientific research as has been emphasized in almost every important meeting held on the subject. Unfortunately, and often not recognized, the fact is that in the absence of effective extension services much of the results of research will simply remain in experimental stations. One can identify several examples where industry has not been able to take advantage of the results of research. This may be due to the lack of appropriate follow-up action, or defects in the structure and nature of the extension services.

2 Some general considerations

The need for research in aquaculture is generally accepted, but the nature of research and how it should be carried out remain somewhat unclear. Aquaculture involves the control of adverse conditions that usually cause high mortalities, and inhibit rapid growth and reproduction in selected organisms. Real husbandry would involve maximum control of the factors that limit production, and would include genetic manipulation of the organism to improve its qualities and suitability for culture. Aquaculture research has to be directed toward producing the science on which husbandry practices can be based.

Two categories of research relevant to aquaculture need to be considered: (*i*) applied research and development; and (*ii*) directed basic research. In applied research, science is applied to the solution of practical problems and most aquaculture research falls into this category. A good deal of it, however, is directed toward gaining an understanding of the under lying phenomena necessary for solving practical problems; this forms directed basic research. Developmental research, as an extension of applied research, takes into account the fact that in applying recognized principles in industry, additional research may be necessary to adapt laboratory procedures to large-scale operations.

Instead of trying to classify research, one may try to determine the different levels of aquaculture research in which the prospects of success and the anticipated difficulties are of a different order, in somewhat the same way as has been done in agriculture research (Salmon and Hanson, 1964). Research at a relatively simple level would be designed primarily to use known principles and derive answers to the aquaculturist's immediate problems; concerning, for example, induced breeding of fish, stocking densities, fertilizer use in ponds, feeding and management practices. At a deeper level would be observations or experiments to determine why certain practices are better than others. At a third, and even deeper level, would be research designed to determine the basic physiological or chemical reasons for certain phenomena, such as the inability of some organisms to attain maturity in confined waters, or the need for specific elements in the nutrition of particular organisms, or the mode of inheritance of animal and plant characteristics including resistance to disease and environmental hazards. Such research is relatively more expensive, difficult and time-consuming. At a fourth and still deeper level might be research to obtain a better understanding of the reproductive physiology, the nature of genes, development of toxicity in certain organisms, *etc.* This type of research needs a high level of scientific expertise and sophisticated equipment and facilities. Distinguishing between these four levels of research does not imply that they should be conducted separately or independently. In fact, research at more than one or even at all levels may well be carried out in the same institution. It is, however, important to ensure that the level of research is appropriate for the solution of the problem under consideration. It is in this context that the categorization of aquaculture research becomes relevant, for the nature of the problem or the phenomenon to be studied will determine the type of research required. It is necessary, therefore, to establish in advance what the problems are and what is sought to be achieved as a result of study.

Trained scientific personnel, adequate equipment and facilities and indeed a scientific atmosphere are essential for development of research at any level; but in the ultimate analysis much of these devolve on appropriate funding. In spite of the general interest, research funding in the aquaculture sector has been very limited. To a cerain extent, this is ascribable to the unfamiliarity of funding agencies with aquaculture and its potential for future development. Considerable scepticism is sometimes expressed about the economic viability of aquaculture, the possibility of producing aquafoods at prices that the common man can afford and even the usefulness of some of the research. In this respect, aquaculture cannot compare with agriculture or even conventional fisheries, where production is widely spread out and, because of a well accepted need to produce, governments are willing to subsidize production heavily and provide other necessary incentives, including research and extension support. Although the current aquaculture production of over 6 million tons a year is substantial, particularly so since almost all of it is used as human food and its value is comparatively high, large-scale production is restricted to a small number of countries. This is a question of what comes first: the chicken or the egg? However, it clearly shows the need for promoting a production programme using the existing technology where feasible, in order to attract the necessary support for research and to clear the misconception among some that aquaculture is still in an experimental stage. It may also be prudent to

orient initial research in most countries to the solution of the more important practical problems facing production, so that the impact of research on production can be demonstrated in a reasonable period of time. This can be expected to facilitate support for long-term deeper research necessary for even greater development of the industry.

A further major consideration in regard to aquaculture research is its multidisciplinary nature and the extent of facilities required for experimental and pilot operations. Aquatic animals used for culture have a number of physiological advantages compared to land animals, such as low-energy needs for growth and maintenance; but, these are to a large extent counter balanced by some very serious limitations imposed by the aquatic medium, such as susceptibility to pollution from external sources or by the metabolites excreted by the animal itself.

The nature of the medium in which aquatic animals live also imposes restrictions on the introduction of non indigenous species for culture. Both agriculture and animal husbandry are based on a limited number of species which have already been widely distributed through human transfer, but there are some serious objections to international exchange of fish and shellfish. In the aquatic environment, even under controlled conditions, it is often extremely difficult to eradicate an unwanted species and the effects of escape of prolific species into natural water bodies are often difficult to observe and even more difficult to predict. It also requires caution and technical expertise to prevent the fortuitous introduction of pests, parasites and diseases through such introductions. The trend has, therefore, been to use locally occurring species with the result that present production is based on hundreds, rather than a few, species. This calls for much greater research effort, as the development of appropriate technology for the culture of even a small number of species requires more effort and resources than most existing institutions can now afford.

3 Aquaculture research needs

Since aquaculture systems vary so considerably in the species used, environmental conditions required and culture methods followed, it is extremely difficult to outline all the types of research that need to be carried out. However, the main elements of a research programme can be listed as follows:

(*i*) The selection of species for culture and study of the general features of their biology.

(*ii*) Selection of sites for culture based on topographical, soil, hydrological, meteorological and biological data.

(*iii*) Design and construction of culture facilities, including hatchery and farm installations and implements.

(*iv*) Reproduction of the species and mass production of seed with minimum mortality.

(*v*) Determination of appropriate stock densities and combinations of species and size groups for optimal production.

(*vi*) Nutrition, food and feeding, including the mass production of natural food and the formulation and preparation of suitable artificial feeds to meet the nutritional requirements and appropriate methods of feeding so as to obtain optimal conversion ratios and high yields.

(*vii*) Control of environmental conditions and management of culture installations, including reconditioning and re-use of water, maintenance of optimal temperatures, oxygen content, *etc.*

(*viii*) Diagnosis and control of diseases including factors responsible for the occurrence of diseases, such as stress, contamination by pathogenic organisms, *etc.*

(*ix*) Predators and their control.

(*x*) Genetics to develop suitable strains with desired qualities, such as hardiness, resistance to diseases, and enhanced food conversion.

(*xi*) Bio-energetics with a view to determining optimum age or size to which the organisms should be grown, best time to harvest, best utilization of food and evaluation of other production techniques.

(*xii*) Harvesting and post harvest technology.

(*xiii*) Marketing of aquaculture products.

(*xiv*) Economics, including the comparative economics of different techniques applicable in a production system and the economics of the system as a whole, determination of economic size of operations and construction of appropriate models to determine the inter-relationship of variables and their values in each technology, sensitivity of output measures, *etc.*

The above outline illustrates the wide spectrum of interrelated research required to develop a system of aquaculture or to improve the existing systems.

A number of attempts have been made recently to review the status of research in aquaculture and future needs on a national as well as international basis. The most recent national studies appear to be those made in the USA and Canada (NOAA/NMFS and Sea Grant, 1975; Pritchard, 1975). Reviewing the work carried out during the last decade in the USA, the NOAA study states that 'Past approaches . . . were highly skewed toward biological research, often for purposes of management, not aquaculture. Most efforts were sporadic and poorly funded. Few, if any, engineering, economics or market-related information needs were met and a systems approach was never applied to aquaculture'. It recognized the need to channel the diverse efforts spread over some 20 agencies or organizations into a coordinated programme. The basic problems recognized in this study apply to a large majority of countries.

According to information compiled by FAO in 1971 and 1973, there are 56 institutions in different countries meant solely for aquaculture studies and 103 institutions where aquaculture forms a part of the research programme. A number of these institutions, especially in developing countries, are small stations attached to experimental or demonstration farms. They have no more than a few technicians to undertake investigations and very limited facilities for research or pilot-scale operations.

A detailed review of research needs in aquaculture with particular reference to the needs of developing countries was made by a Working Group on Aquaculture appointed by the Technical Advisory Committee (TAC) of the Consultative Group on International Agricultural Research (CGIAR). The Group at its meeting in Spoleto, Italy, 4–8 February 1973, recognized the need and high priority for interdisciplinary research directed toward overcoming the main constraints on wider application of existing culture systems and to improve the techniques for increasing production (TAC, 1973). The main culture systems that deserve to be studied in different regions and the main problems to be investigated were identified by the Group. A

TAC Sub-Committee on Aquaculture later prepared specific proposals for international research in the field of aquaculture (TAC, 1974). Referring to the nature of research required, the Sub Committee expressed the following opinion: 'Aquaculture, like other agricultural production systems, has strong feed-back components. For instance, improvement in seed supply requires new food or feed production techniques as well as changes in engineering and management. The same is, of course, true when new strains or varieties emerge from the research effort. Thus, the research in any one culture system must be considered as indivisible and selection of certain research problems for solution at the expense of others would be technically and economically imprudent'. It reaffirmed that 'an integrated systems approach to such research is essential if a major impact on aquaculture production is to be made in a reasonable period of time'. The possibility of centralizing all major research on aquaculture in an international centre was considered and the Sub Committee was of the view that it would be counter-productive to do so, because of the differences in species cultured and the need to study the various aspects 'in the set of environmental conditions in which the particular species occurs and those in which it has to be reared'. The Sub Committee therefore recommended the establishment of coordinated regional networks of aquaculture centres for research and training in Africa, Asia and Latin America, consisting of regional centres for long term systems-oriented interdisciplinary research linked to selected national centres for research on problems of local nature, field tests of techniques developed at the regional centres and adaptation of these to meet local requirements.

The establishment of such networks does involve appreciable investments but far less than what is invested now in allied fields like agriculture or animal husbandry. These proposals still remain unimplemented. Questions have been raised as to whether enough personnel are available for advanced aquaculture research. It is true that the majority of aquaculture scientists are general biologists by training and there is a scarcity of specialists with experience in aquaculture engineering, economics, or the biological fields like genetics and nutrition. But this is not an argument against the establishment of research institutions as this problem can be solved through suitable organizational arrangements. Interdisciplinary research is generally based on teamwork and, if a team can have a core of aquaculture scientists to provide orientation and guidance, the requirements for some of the specialists can be met by borrowing from allied disciplines, as for example, agriculture or irrigation engineers, agricultural economists, animal and plant geneticists, veterinarians, animal nutritionists, and animal feed technologists. Institutions with adequate research facilities, challenging research programmes and satisfactory working and living conditions can be expected to attract capable scientists and technologists if imaginatively administered. Such institutions can also offer the opportunity for young scientists to gain experience through participation in research programmes.

As a part of the activities of the FAO/UNDP Aquaculture Development and Coordination Programme, a series of planning workshops were held in Africa, Asia and Latin America in 1975 (FAO/UNDP, 1975, 1976 and 1976a). Participants from 34 developing countries prepared ten-year plans for aquaculture development in their countries, which included in many cases the identification of research requirements and means of implementing research. Considering the investments in terms of scientific manpower, equipment and facilities required for some of the long-term detailed research, all of the workshops proposed the organization of such research on a regional basis. Because of the diversity of species cultured, and the need to develop technologies to suit different ecological and economic conditions, it was considered impractical to centralize aquaculture research in a single international centre. They proposed that one existing centre in each of the three regions (Africa, Asia and Latin America) be developed into a regional research and training centre. Selected national centres were recommended to be strengthened for undertaking research on problems of national or local importance and close linkages established between regional and national centres forming three regional networks enabling free exchange of expertise and experience. Thus, both the TAC Group of aquaculturists and the representatives of developing countries that participated in the regional workshops have accepted the concept of systems oriented research through regional networks. FAO has prepared draft plans for the establishment of such networks in Africa, Asia and Latin America and efforts are being made to obtain necessary funding to implement these plans.

As a good number of countries have perspective development plans and have already selected the production systems, it is now possible to select the high priority systems for integrated research. Since these are systems that have already been tried on pilot or production scale, the identification of problems to be solved is also relatively easy; in most cases this has already been done.

4 Extension services

The importance of extension services in aquaculture development will become obvious when one considers the analogy of agriculture, where effective application of improved farming methods has been achieved through well organized extension work. Two levels of extension work are often involved in aquaculture: one for the transfer of the results of scientific research to the field through field technicians and the other for the application of new and improved methods in production programmes through assistance and advice given to farmers. A two-way exchange of experience between research scientists and field technicians is of mutual benefit: it helps the prompt application of research results in the field, and the research centres get feedback in the form of results of field applications of laboratory techniques and, more importantly, knowledge of problems faced by aquaculturists in the field. At the second level, extension work involves provision of direct assistance and advice to aquaculture practitioners. Such work is of special significance in small-scale rural aquaculture. The extension agent has to be an excellent technician with the personal qualities and appropriate attitude to work with farmers and persuade them to employ new and improved technology. He will, therefore, need specialized training in extension methods, besides having knowledge and practical experience in aquaculture.

While the technical knowledge and personal qualities of extension agents are key factors, the organization of extension services is of equal importance. Besides the advice and assistance that an extension agent may provide through

periodic visits to a farm, his services have to be available to the farmer at short notice to deal with emergencies; and this necessitates the provision of an adequate number of agents at the community level, depending on the size and distribution of production units. The extension service should have institutional backing to provide the various services that the farmers will need, such as selection of sites, design of ponds and other culture facilities, soil and water analyses, diagnosis of disease and control measures, and periodic health inspection. Financial assistance and credit provided to farmers should also be closely linked to extension services.

The availability of suitable audio-visual aids is of decided importance in effective extension work. There is a great scarcity of instructional films, film strips and other aids for use in training of aquafarmers. Preparation of such aids as well as the production of handbooks in different languages deserve priority attention.

A well organized information system is an important requirement for effective extension work, to the same extent as it is for proper scientific research. The extension agent should have a ready source of information to keep himself well informed on new developments in the field. An efficient system for collection, storage and retrieval of information is complex and expensive and therefore it might be advisable to organize it on a regional or international basis. However, arrangements can and should be made for prompt retrieval of such information for national use by research and extension personnel.

5 Conclusion

For achieving the projected five- to ten-fold increase in world aquaculture production through transfer of technology, improvement of existing technology and the development of new techniques and systems, appropriate levels of interdisciplinary research are essential. The diffused monodisciplinary type of research carried out in isolated stations or laboratories can have only limited impact on aquaculture production. Although the organization of such research cannot be inexpensive, the benefits to be derived from it are bound to be proportionately very much higher than from the fragmented efforts currently undertaken.

A number of agencies have shown interest in aquaculture research and some of them are providing modest support for certain research programmes, *eg*, the United Nations Development Programme (UNDP), United States Agency for International Development (US-AID), International Development Research Council (IDRC), the Canadian International Development Agency (CIDA), and the International Foundation for Science (IFS) in Sweden. The newly established International Center for Living Aquatic Resources Management (ICLARM) is also expected to provide support for aquaculture research. The efforts of the Technical Advisory Committee (TAC) of the Consultative Group on International Agricultural Research (CGIAR) to formulate an international research programme have already been referred to. There are a number of other agencies like the Norwegian Agency for International Development (NORAD), Swedish International Development Authority (SIDA), the World Bank Group and the Area Development Banks that have interest in aquaculture research. If these agencies decide to co-operate with each other, the financing of the network of research centres is likely to become relatively easy. In fact, the FAO/UNDP Regional Workshop on Aquaculture in Asia (Bangkok, Thailand, 1–17 October 1975) has recommended that a meeting of the agencies involved and interested in providing assistance in the field of aquaculture should be convened to discuss effective co-operation in the establishment and operation of the proposed regional network of research centres.

Multilateral or bilateral assistance can only supplement or strengthen national efforts. The organization of research and extension services form the responsibility of governments and appropriate priority has therefore to be given to this in the public sector development plans. In advanced countries, the industry may be able to carry out research or, at least, partially support it. The co-operation of industry and academic institutions should, therefore, be obtained to facilitate the implementation of research programmes.

The laboratory and field facilities of the regional and national research centres could be used for training of the core personnel needed for aquaculture development. Besides the in-service training of young scientists as aquaculture research workers, the regional centres could be used for the training of aquaculturists. The national centres will be most suitable for the training of extension workers and such specialized training facilities could go a long way to improve extension services for aquaculture development.

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A Role for Private Contract Research in the Development of Fish Farming

Ian S. Macfarlane

Abstract

If the potential of fish farming as a means of food production is to be realized, an increase in the level of research to this end is necessary. The success of research will be measured by effective development of its results into practical technologies that can be used by fish farmers

Private contract research organizations are specialist bodies providing a range of research and development services to private or public industry. They undertake work on a proprietary basis and are typically highly efficient, flexible, responsive to their clients' requirements, and cost effective in terms of fixed capital and manpower utilization. Conducting a variety of projects, often simultaneously, enables them to build up a reservoir of expertise in a variety of related subjects which is available to their clients.

Application of the principles of private contract research to fish farming suggests that it could provide an integrated, efficient, practically oriented service which would encourage investment by public and private organizations. Such investment could be at one or more levels and might involve all stages of development from promotion and feasibility assessment, through fundamental and applied research, testing of methods and supplies, pilot scale production and design, to full-scale production and beyond. Such organizations, operating in a complementary role with existing research and development agencies, could do much to ensure increased food production from fish farming.

Rôle des recherches contractuelles privées dans le développement de la pisciculture

Résumé

Si la pisciculture doit être pratiquée aux fins de la production alimentaire, il faut pousser les recherches dans ce domaine. Le succès des recherches se mesurera aux progrès effectivement apportés aux techniques susceptibles d'être utilisées par les éleveurs.

Les organisations privées de recherche contractuelle sont des organismes spécialisés fournissant à l'industrie privée ou publique toute une gamme de services dans les domaines de la recherche et du développement. Elles se chargent de travaux pour un mandant particulier et sont par définition très efficaces, souples, attentives aux desiderata de leurs clients et rentables du point de vue de l'utilisation du capital fixe et de la main d'oeuvre. Le fait qu'elles s'occupent parfois simultanément, de projets variés, leur permet de se créer un fonds de connaissances, au bénéfice de leurs clients, dans une gamme variée de sujets voisins

Si l'on pratiquait des recherches privées contractuelles en matière de pisciculture, on pourrait assurer un service intégré, efficace, pratique, qui encouragerait les organisations publiques et privées à investir. De tels investissements pourraient se faire à plusieurs niveaux et porter sur tous les stades du développement, de la promotion et de l'évaluation de la faisabilité à la production à grande échelle et au-delà, en passant par la recherche fondamentale et appliquée, l'expérimentation de méthodes et d'inputs, la production pilote et son organisation. Ces services, dont le rôle est complémentaire de celui des organismes existants dans le domaine de la recherche et du developpment, pourraient participer très utilement à l'accroissement de la production alimentaire par la pisciculture.

Función de las investigaciones privadas mediante contratos en el desarrollo de la piscicultura

Extracto

Para aprovechar las posibilidades de producción de alimentos que ofrece la piscicultura es necesario aumentar las investigaciones. El éxito de las investigaciones se mide por la traducción eficaz de sus resultados en tecnologías prácticas que puedan utilizar los piscicultores.

Las organizaciones privadas de investigación por contrato son órganos de especialistas que ofrecen una vasta gama de servicios de investigación y desarrollo a la industria privada o pública. Realizan sus trabajos con carácter privado y se caracterizan por su gran eficiencia, su flexibilidad, su adaptabilidad a las necesidades de sus clientes y su eficacia en función de los costos (capital fijo y utilización de mano de obra) Como realizan proyectos muy diversos, a menudo simultáneamente, pueden acumular experiencia sobre diversas cuestiones afines, que está a disposición de sus clientes.

La aplicacion de los principios de la investigacion privada por contrato a la piscicultura sugiere que ese sistema podría ofrecer un servicio integrado, eficaz y práctico, que fomentaría las inversiones de organizaciones públicas y privadas. Dichas inversiones podrían realizarse a uno o más niveles y podrían abarcar todas las fases de desarrollo, desde la promoción y la evaluación de la viabilidad hasta la producción a plena escala, pasando por las investigaciones fundamentales y aplicadas, los ensayos de métodos y suministros, la producción en escala piloto y la planificación. Esas organizaciones de investigación, que desempeñan una función complementaria respecto a los organismos de investigación y desarrollo, podrían contribuir en forma importante al aumento de la producción de alimentos procedentes de la piscicultura.

1 Requirements for research and development in fish farming

It is generally accepted that there is a need for increased research and development effort toward realization of the potential of aquaculture. Pillay (1973) suggests that most of the present technology has developed by trial and error rather than by scientific research, and he has identified 'an urgent need for concerted and well organized research'. The expansion of fish production by farming will depend upon an expansion of such research effort. The key factor in assessing the value of this effort will be the effectiveness of the methods by which research findings are developed to the stage of practical technology, and their impact on the development of fish farming. The co-ordination of research and experimentation with the requirements of the fish farmer, the exploitation of research results as commercially viable techniques, and the establishment of the infrastructure within which such exploitation may take place, will be far more important than the research results *per se*.

Development of fish farming up to the stage of viable production will take place via a series of steps. To some extent these will overlap one another but the following development stages from project formulation to viable production may be defined: (*i*) project promotion, formulation, feasibility assessment and planning; (*ii*) fundamental research and discovery of biological criteria; (*iii*) applied research and field testing of production methods and supplies; (*iv*) pilot-scale production and definition of production methods; (*v*) design, construction and commissioning of production facilities; (*vi*) start-up of production; (*vii*) maximization of production.

This progression will apply irrespective of whether the ultimate objective of development is private profitability, as in much of the developed world, or social profitability, as in less highly developed regions. Nevertheless, differences in the approach to research will depend to some extent upon the role which the ultimate development is required to fill. Shepherd (1974) illustrates these different roles by contrasting the situation, typical of some of the less developed countries, in which aquaculture is required to produce a supplementary source of animal protein in regions where diets might otherwise be nutritionally inadequate, with the situation in more highly developed economies in which capital-intensive schemes involving high cost, high value species destined for the upper end of the market, may be chosen. Such roles are usually decided on the basis of economic criteria.

In cases where the aim of research is to provide a subsistence-type fish farming activity, labour is usually relatively cheap and available and inexpensive, biologically inefficient systems of fish production are often acceptable. Research may be concentrated in the areas of feasibility study, development of pilot-scale production methods, and problems of full-scale production. In contrast, where the result of research is expected to be an expensive and intensive form of fish culture, as in the highly developed regions of the world, there may be a bias toward research of a fundamental type, and applied research, product screening, field testing, and economic design and pilot-scale studies.

Pillay (1973) states that 'action by the private sector, due to its proprietary nature has, unfortunately, not spread very far and has contributed little to the overall development of the (aquacultural) industry'. It is true that private industry has found it difficult to see a part for itself in the development of fish culture technology, and unlikely that it will do so in relation to those underdeveloped regions of the world where the low economic status of the population precludes the existence of a true demand, as opposed to need, for the products of fish farming. Financial support for development in these regions and support from international bodies will continue to be very important.

The strategy of research has been defined for a number of established industries, *eg*, the chemical industry (Baines, Bradbury and Suckling, 1969). The technology of fish farming is more akin to that of agriculture than of industry. Thus, it is a diverse field whose form and efficiency depend upon such factors as local conditions of climate, terrain, water quality and availability, economic conditions, market requirements and available expertise. Only seldom is there a specific problem requiring research solutions of a basic, fundamental or academic type. More commonly the need is for steady progress in the development of husbandry and management techniques, facility design and equipment, or of improved supplies in the form of foodstuffs, basic stock, construction materials and pharmaceuticals. Despite a requirement for more basic research in certain areas, most research needs are best met by target research where the need is first defined and then satisfied by a variety of forms of research activity, often of an interdisciplinary nature. The need may be complex but it is usually capable of definition in terms of economic and technical criteria.

Frequently a gulf exists between the fundamental research worker and the worker in technological research. Aquaculture research is no exception and it is common for research effort to be concentrated upon one particular species, geographical location or culture method. Such research will have no practical impact upon the development of fish farming unless it is part of a properly planned and meaningful programme aimed at a complete development of techniques available to, and usable by, the fish culturist. However, there are already a number of organizations active in the development of fish farming at various levels; these include FAO, a variety of government organizations, universities and other agencies. The work of these bodies is important, and for private contract research to be seriously regarded as a valuable additional method of stimulating fish farm development it must have a special contribution to make which is not available elsewhere, or which could not be made available more effectively in some other way.

2 Private contract research

Private contract research organizations generally specialize in particular fields of activity, *eg*, toxicology, electronics, and engineering; or in particular industries, *eg*, mining, the motor industry, and the building industry. They operate a service for their clients which may include any, or several, of the stages (*i*) to (*vii*) listed in section 1 above, but generally specialize in stages (*i*) to (*iv*), often with emphasis on testing or screening aspects of research. Work is always undertaken on a proprietary basis but since clients may be governments or other state organizations, as well as private companies, public corporations or individuals, the information which they generate may, or may not, remain confidential to the client. Usually a private contract research body will provide its services simultaneously to a number of different contractors, some of whom may be in direct commercial competition. Two main considerations stimulate the use of contract research, rather than the conduct of 'in house' research. Firstly, it is often financially attractive since the contract organization, conducting several projects simultaneously, can be highly cost-effective in terms of manpower and fixed capital utilization, and can usually undertake projects more cheaply than the contractor himself. Where high fixed capital costs are involved, the smaller company would frequently be unable to do research at all, other than by contracting it out. Secondly, the contract research company is valuable in acting as a reservoir of knowledge and information. Whilst the results of any research project are confidential to the client, each client will benefit from the pool of expertise developed by virtue of the contracting organization's activities for other clients. By its nature, a contract research organization is extremely flexible and responsive to the requirements of its clients. It is able, therefore, to respond rapidly to those requirements and, having the basic equipment necessary to undertake the work, can usually adapt to new demands quickly without incurring large additional costs for plant. In general, the contracting organization is smaller than any of its individual clients, freer from bureaucratic inertia and better able to cross political and geographical barriers.

The approach of a private contract research body to questions of secrecy can be flexible. In the most extreme cases a client's name may require protection; more commonly, his line of research or product is secret, or it may be that only the results of his work will require confidential treatment. Where work is done for national governments or other government bodies, or where a supplier is developing a product for sale, the requirements may not be for confidentiality but for rapid dissemination of new information. In these cases the contracting organization may be required to play a part in disseminating information rather than in protecting it.

3 Private contract research in fish farming

Private contract research has proved its value in many fields where organizations offering this facility frequently provide an attractive service to industry. Fish farming requires more research effort and better use of the results of this effort. An organization which can provide a service to accommodate the diverse nature of fish farming, through all the necessary stages of research and development, is difficult to envisage. Private contract research, with its high efficiency, close contact with the requirements of its clients, flexibility of approach, adaptability and ability to operate freely in a variety of different social, political and geographical situations might provide such a service and may be a mechanism by which the advance of fish farming technology can be achieved more effectively and more rapidly. The areas where private contract research can be successful in assisting the development of fish farming can be summarized as:

(*i*) Promotional activities and making available a route by which new organizations may participate in fish farming and its development. Many large commercial organizations

are only reluctantly drawn into participation in a new field. This is particularly so where investment can lead to an unacceptable level of commitment too early in the life of a project. The use of contract research facilities minimizes commitments and enables an organization to assess the value of a project whilst remaining remote from it, so that the consequences of its failure are limited. Fish farming is not an obvious diversification possibility for many commercial companies. They are more likely to begin work in this field, which is new to them, if they are able to do so without the need for an excessive level of direct involvement.

To most large organizations fish farming may appear a small-scale activity, capable of expansion only within quite close limits at any one location. The overheads of large organizations are frequently too large to permit them to participate in such small-scale activities, especially where research and development is required. The smaller size of a fish-farming contract organization, and its inherent efficiency, means that overheads may be reduced and the initial requirement for investment minimized. This could make the difference between acceptance and rejection of a fish-farming investment opportunity by a large public or private organization.

(*ii*) At the feasibility assessment stage, by the collection and correlation of data relevant to the project, and assessment of the potential for success. During the initial stages of development of any fish-farming project a wide range of expertise must be brought to bear on the problems of planning. The contract research body, with its experience of a variety of fish-farming methods in a wide range of geographical and climatic situtations, can contribute significantly to this planning phase. Thus the ability to operate on a worldwide basis will ensure that experience is drawn, where applicable, from one region or species, and applied to similar situations in another region or with another species. It is doubtful if any organization, other than one deeply involved with the practical problems of fish cultivation in a variety of different stituations, can fill this role effectively.

(*iii*) During the fundamental research stage, stimulation of academic or basic research activity and co-ordination of such activity with practical needs.

(*iv*) Development of techniques, and testing of production methods and supplies on a proprietary basis. It is often difficult for other research and development organizations to undertake their work on a proprietary basis. Without the ability to gain some commercial advantage over competitors, many commercial organizations which might contribute to the overall development of fish farming, either as producers or suppliers, will not do so. Thus, the ability of a contract research organization to undertake proprietary research results in developments which might not otherwise take place. Although the concepts of secrecy in research and rapid development of a new industry may seem incompatible, in practice, results seldom remain secret once they are applied to a commercial project, and the resulting improvement in knowledge usually quickly results in advances in a wide range of similar or associated projects.

(*v*) Development of pilot-scale production projects, definition of methods on the production scale and development of working production techniques.

(*vi*) Utilization of a background of expertise in a wide variety of different production systems, materials, and geographical, climatic and social conditions in the design, construction and commissioning of facilities for fish production.

(*vii*) Provision of a supporting service to new developments as production begins. This may include provision of supplies and stock, staff training and resolution of early organizational problems as they arise.

(*viii*) Provision of a continuing service of refinement and improvement of techniques aimed at maximization of production. Aquaculture, although by no means a new method of food production, is so far relatively undeveloped. In this situation quite small technological advances can have considerable impact upon the efficiency of fish production and the range of application of fish-farming methods. The adaptability of the contract research organization might make it a highly desirable route by which knowledge may be disseminated, and this would result in rapid exploitation of new technology over a wide range of field situations. There is also a role in relaying information on the nature of practical farming problems back to fundamental or applied research workers.

4 Conclusions

A private contract research service, operating in a complementary role with existing research and development agencies, might encourage more investment in the development of fish farming from government and private sources. By providing an efficient, practically-oriented service, co-ordinated with the true needs of producers and suppliers, it could do much to assist in extending fundamental research into field tests, pilot scale projects, production farms, and eventually, increased food production from fish farming.

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International Aspects of Disease Control in Aquaculture

P. Ghittino

Abstract

Although disease in cultivated aquatic organisms is one of the major biological risks facing aquaculture development, its importance is often under estimated. While knowledge of diseases of freshwater fish has increased rapidly over the past twenty years, much less is known about diseases of marine fish, molluscs, crustaceans and seaweeds.

Several international organizations, such as OIE, EIFAC and FAO have been actively studying fish disease problems associated with international transfers of live fish and eggs, and WHO has been interested in public health problems associated with fish disease. A recent survey of laws and regulations showed that the majority of countries exercise some form of control on shipments, but the effectiveness of health control measures varies from satisfactory to ineffective.

A Symposium on the Major Communicable Fish Diseases in Europe

and their Control organized by FAO/EIFAC with the support of OIE in 1972, concluded that, (*i*) there was a need for international control of traffic in live fish and fish eggs, (*ii*) the most effective control measure was inspection at source combined with certification; and (*iii*) aquaculture establishments under surveillance and certified free from diseases were the ideal situation.

Following a recommendation by EIFAC (1972) and enquiry of concerned Member Governments, a Government Consultation on an International Convention to Control the Spread of Major Communicable Fish Diseases was convened by FAO in 1974. The majority of delegates at the Consultation recognized the need for a Convention, and a further legal/technical consultation on the subject.

Meanwhile, a number of governments as well as national and industrial organizations are taking steps to control the spread of disease in food, sport and ornamental fishes as well as of molluscan parasites.

In instituting and maintaining rules for health control in cultivated aquatic animals and plants, knowledge must be obtained concerning the identification, nature and occurrence of the most dangerous pathological organisms affecting them. Reliable and standardized diagnostic methods, and criteria for disease-free status of aquaculture establishments must be developed. First consideration must be given to fish diseases which have already been thoroughly considered by national and international organizations. After that other diseases of freshwater fish and those of marine fish, cultivated molluscs, and seaweeds should receive attention.

Continued co-operation by the international organizations concerned with aquaculture will provide protection of aquaculture stocks and development of a sounder industry.

Aspects internationaux du contrôle des maladies en aquaculture

Résumé

Bien que les maladies des organismes aquatiques d'élevage représentent, sur le plan biologique, l'un des principaux risques liés au développement de l'aquaculture, leur importance est souvent sous estimée. Si les connaissances relatives aux maladies des poissons d'eau douce se sont rapidement enrichies au cours des vingt dernières années, par contre on en sait beaucoup moins sur les maladies des poissons de mer, des mollusques, des crustacés et des algues.

Plusieurs organisations internationales, telles que l'OIE, la CECPI et la FAO étudient beaucoup les problèmes d'ichtyopathologie associés aux échanges internationaux de poisson et oeufs de poisson vivants et l'OMS s'intéresse aux problèmes de santé publique liés aux maladies des poissons. Une enquête récente sur les lois et règlementations en vigueur a montré que la majorité des pays exercent une certaine forme de contrôle sur les expéditions, mais que l'efficacité des mesures de contrôle sanitaire varie entre un niveau satisfaisant et l'inutilité totale.

Un symposium sur les principales maladies transmissibles des poissons en Europe et la lutte contre ces maladies, organisé par la FAO/CECPI avec le soutien de l'OIE en 1972, est parvenu aux conclusions ci après; (*i*) il est nécessaire d'instaurer un contrôle international des échanges de poissons vivants et oeufs de poisson; (*ii*) la mesure de contrôle le plus efficace est l'inspection à la source, associée a la certification; (*iii*) des établissements d'aquaculture placés sous surveillance et certifiés exempts de maladies représentent la situation idéale.

Pour donner suite à une recommandation de la CECPI (1972) et aux demandes de renseignements de pays membres concernés, une consultation gouvernementale a été convoquée par la FAO en 1974 pour envisager l'établissement d'une convention internationale pour la lutte contre la propagation des principales maladies transmissibles des poissons. La majorité des délégués a la Consultation ont reconnu la nécessite d'une Convention et une nouvelle consultation juridique/technique sur la question sera tenue conjointement par la FAO/OIE en 1976, au siège de l'OIE à Paris.

En attendant, un certain nombre de gouvernements ainsi que d'organisations nationales et industrielles prennent actuellement des dispositions pour enrayer la propagation des maladies affectant les poissons de consommation, les poissons de pêche sportive et les espèces ornementales, ainsi que la propagation des parasites chez les mollusques

Pour instaurer et faire observer des règles de contrôle sanitaire applicables aux animaux et plantes aquatiques d'élevage, il importe que nous enrichissions notre savoir afin de pouvoir identifier et déterminer la nature et la fréquence des organismes pathogènes les plus dangereux. Il faudra mettre au point des méthodes de diagnostic fiables et les normaliser, et définir des critères permettant de certifier que les établissements d'aquaculture sont exempts de maladies. Il faudra considérer en premier lieu les maladies des poissons qui ont deja fait l'objet d'un examen approfondi de la part des organisations nationales et internationales. On passera ensuite à d'autres maladies des poissons d'eau douce et à celles des poissons de mer, des mollusques d'élevage et des algues.

Une coopération constante entre les organisations internationales qui s'intéressent à l'aquaculture permettra d'assurer la protection des stocks d'élevage et le développement d'une aquaculture plus rationnelle.

Aspectos internacionales de la lucha contra las enfermedades en acuicultura

Extracto

Aunque las enfermedades de los organismos acuáticos cultivados constituyen uno de los principales peligros biologicos para el desarrollo de la acuicultura, con frecuencia se subestima su importancia. Mientras los conocimientos sobre las enfermedades de los peces de agua dulce han aumentado rapidamente durante los ultimos veinte años, se sabe muy poco sobre las enfermedades de peces marinos, moluscos, crustáceos, y algas

Varias organizaciones internacionales, como la OIE, la CAEPC y la FAO se han dedicado activamente al estudio de los problemas ictiopatológicos determinados por las transferencias internacionales de peces vivos y huevos, y la OMS se ha interesado por los problemas sanitarios relacionados con las enfermedades de los peces. En un reciente estudio de las leyes y reglamentaciones en este campo se ha hallado que la mayoria de los paises controlan de una u otra forma los embarques, pero con muy diversa eficacia: a veces las medidas resultan satisfactorias y otras veces totalmente ineficaces.

En el Simposio sobre las Principales Enfermedades Transmisibles de los Peces en Europa y la Lucha contra las Mismas, organizado por FAO CAEPC, con apoyo de la OIE, en 1972, se llegó a la conclusion de que (*i*) era necesario un control internacional del trafico de peces vivos y huevos de peces; (*ii*) la medida de control más eficaz era la inspección en el punto de origen, acompañada de la emision de certificados, y (*iii*) lo ideal era contar con explotaciones acuicolas de las que, con la oportuna vigilancia, se pueda certificar que están exentas de enfermedades

Siguiendo una recomendación hecha por la CAEPC (1972), y tras consultar a los Estados Miembros interesados, la FAO convocó en 1974 una Consulta Gubernamental sobre un Convenio Internacional para Combatir la Difusion de las Principales Enfermedades Trasmisibles de los Peces. La mayoria de los delegados que asistieron a la Consulta reconocieron la necesidad de dicho Convenio, y en 1976 se celebrara en la Sede de la OIE, en Paris, una nueva consulta juridico/técnica sobre la cuestion, patrocinada conjuntamente por la FAO y la OIE

Entretanto, varios gobiernos y diversas organizaciones nacionales e industriales están tomando medidas para combatir la difusión de las enfermedades de los peces utilizados para alimentacion, para pesca deportiva y para ornamento y la propagacion de los parásitos de los moluscos.

Para instituir y mantener normas de control sanitario sobre los animales y plantas acuaticos cultivados, es necesario obtener conocimientos para la identificación, naturaleza y casos de los organismos patológicos mas peligrosos. Es preciso, además, preparar metodos fidedignos y uniformes de diagnóstico y criterios para conceder el certificado de exención de enfermedades a los establecimientos acuicolas. Ante todo, hay que ocuparse de las enfermedades de los peces que han sido ya examinadas a fondo por las organizaciones nacionales e internacionales y posteriormente habrá de prestarse atencion a otras enfermedades de los peces de agua dulce y a las de peces marinos, moluscos cultivados y algas.

La colaboracion continua de las organizaciones internacionales que se ocupen de la acuicultura permitirá proteger las poblaciones utilizadas y desarrollar esa industria sobre bases más sólidas

1 Introduction

Aquaculture is concerned with the propagation and rearing of aquatic organisms under complete human control, involving the manipulation of at least one stage of an aquatic organism's life before harvest in order to increase its production. Many recent publications have provided general reviews of the subject. It is obvious from these that aquaculture has overcome its embryonic stage and much of its formerly empirical character. Nevertheless, many problems remain which hinder its present progress toward the establishment of viable industries, and its very development creates new problems which must be overcome to further its progress. Aquaculture enterprises, like other ventures in agribusiness, are subject to a series of situations which frequently govern the success or failure of such activities, *eg*, lack of technical know-how, scarcity of trained personnel and a need of funds for capital investment. But in addition to these, the cultivation of aquatic organisms faces many biological risks, a feature which differentiates it from many industrial developments and brings it closer to systems of agriculture and animal husbandry. Two major biological risks which threaten aquaculture are instability in provision of water of suitable quantity and quality, and the ever present susceptibility of cultivated animals to disease.

2 Disease in cultivated aquatic organisms

The role of diseases in aquaculture, which may be enormous, is sometimes underestimated. Diseases are important economically because they can cause mass mortalities, reduce production and diminish the quality of aquatic organisms as food. The protection of the stock of cultivated aquatic organisms from diseases must, therefore, receive high consideration in the initiation, development, and intensification of any form of aquaculture. Use of intensive methods which is the general trend of modern aquaculture, is usually profitable only under conditions of high stock density, and in such intensified culture systems, disease assumes more importance. This may, however, also apply to extensive aquaculture, and it should be noted that while prophylactic and curative measures can be undertaken economically in intensive systems, they are much more difficult to use in the more traditional extensive culture.

Knowledge of fish diseases has, in general, progressed rapidly in the past twenty years or so, but this knowledge is based primarily on the diseases that affect fish cultivated in fresh water. Examples of some of the major compendiums on the subject are the publications by Schäperclaus, 1954; Davis, 1961; Reichenbach-Klinke, 1966; Ghittino, 1969, 1970; Amlacher, 1970, 1972; Kabata, 1970; Bullock, 1971; Bullock, Conroy and Snieszko, 1971; Sarig, 1971 and Bauer, Musselius and Strelkov, 1973. Although many diseases of cultured species in freshwater environments are well understood and methods for their control have been developed, the diseases of food fishes in marine water have only received descriptive attention. This aspect of fish pathology, which is as new as is marine fish culture, has been reported upon generally by Sindermann (1970) and the most important diseases occurring in cultivated marine fishes have been summarized by Ghittino (1974a). Since marine fishes are being cultivated more frequently, it is logical to assume that their diseases will also soon be investigated thoroughly and control measures developed.

Mortalities due to diseases in other cultivated aquatic organisms (molluscs, crustaceans, frogs, reptiles and sea weeds) have been reported in the literature, *eg*, by Reichenbach Klinke and Elkan (1965); Iversen (1968, 1969); Sindermann (1970); Snieszko (1970); Honma (1971); Bardach, Ryther and McLarney (1972); Egusa, Guary and Guary (1974).

So far, much emphasis has been placed on curing fish diseases and not enough on disease prevention. Much research is still required to increase understanding of the diseases of all cultured aquatic organisms, followed by development of treatment and prevention.

3 Interested international organizations

The progress of international organizations up to 1972 with respect to the control of fish diseases has been reported in detail by Thompson, Dill and Moore (1973). The following account will briefly recapitulate this history and update it as far as possible. It will be noted in this account that considerably more attention has been paid so far to diseases of fish rather than those of other organisms (Ghittino, 1974b), since knowledge is more advanced in this field. Some patterns of disease control which have been studied for fish have also been proposed recently for other cultivated organisms, such as oysters (Snieszko, 1968), and they would also be suitable in other instances.

3.1 *The International Office of Epizootics (OIE)*

The International Office of Epizootics (OIE), Paris, has stressed the importance of control of fish diseases and of health inspection of fish products since 1960. OIE has formulated an International Zoo-Sanitary Code (concerning mammals, birds, fish and bees) to be considered as a guide to facilitate the work of veterinary services and suggested a 'model' or 'pattern' certificate for use in international trade for live fish and fish eggs. It has established a Permanent Commission for the Study of Fish Diseases which has elaborated an international prophylactic plan for fish diseases, and has organized three symposia on fish diseases (Turin, 1962; Munich, 1965, Stockholm, 1968) (OIE, 1963, 1966, 1968). It has also provided support to the Symposium on the Major Communicable Fish Diseases in Europe and their Control held in Amsterdam, 1972 (section 3.2 below). During the OIE Commission meetings, not only have suggestions been made for international rules (including those for health certificates of origin for live fish and fish eggs), but a list of fish diseases including their nomenclature and diagnostic methods has been presented. In 1968, the OIE included in its International Zoo-Sanitary Code, four communicable fish diseases: infectious pancreatic necrosis (IPN), viral haemorrhagic septicaemia (VHS), infectious dropsy (of carp) (IDC), and furunculosis (F) (Ghittino, 1968). In 1970, whirling disease or myxosomatosis (M) was added to the list (OIE, 1971). The Code reflects suggestions made for the control of diseases in other cultivated animals following the disciplines of veterinary science. OIE believes that fish health certificates will aid international fish exchanges, even though not all producers will immediately like the idea because of possible interference with the trade in live fish.

OIE has recently studied modern prophylactic rules to be applied to the principal communicable fish diseases. At an OIE meeting of experts held in Paris in December 1974, criteria were discussed concerning rules that might be followed in establishing fish farms officially considered free from major communicable fish diseases. From such farms, a veterinary service might issue official fish health certificates at the source (indeed these may be the only ones of significant value) to accompany exports and imports of live fish and fish eggs. Such certificates would attest to the absence of the five major communicable fish diseases mentioned in the OIE International Zoo-Sanitary Code.

'Specific Pathogen Free' (SPF), 'Specific Disease Free' (SDF) and 'Minimum Disease' (MD) conditions were also recognized as feasible in farmed fish, following the same general procedures recently adopted for other cultivated animals, such as swine and poultry. The criteria and methods of official inspection for recognizing water areas and countries as free from selected fish diseases were also discussed. The proceedings of this expert meeting and a review paper will include literature that may be consulted by the administrative bodies concerned and by reference laboratories for fish disease (OIE, 1975). The results of this OIE meeting may also facilitate a programme of measures to be applied to the national and international control of diseases in other cultivated aquatic organisms.

3.2 *European Inland Fisheries Advisory Commission (EIFAC) and the Food and Agriculture Organization (FAO)*

The European Inland Fisheries Advisory Commission is an intergovernmental body of 23 Member Governments with

the Secretariat furnished by the Food and Agriculture Organization of the United Nations (FAO). Since its Second Session (Paris, 1962) it has studied the problem of controlling fish diseases transmitted through import and export of live fish and fish eggs. At its Fourth Session (Belgrade, 1966), the Director-General of FAO was asked to make an analysis of laws and regulations concerning imports and exports of live fish and fish eggs, including the practice of issuing certificates of origin and health. It was also suggested that the Commission—as an interim measure—seek approval through FAO of Member Governments for the adoption of a common form of health certificate for import and export of fish eggs. It was further emphasized that the closest possible co-operation and co-ordination be maintained with OIE during the study.

At the Fifth Sesson of EIFAC (Rome, 1968) some degree of acceptance of the desirability of a health certificate for imports and exports of fish eggs was evidenced. Also, FAO presented a 'Comparative Study of Laws and Regulations Governing the International Traffic in Live Fish and Fish Eggs' (Zenny, 1969) (see section 5). It was manifest from the study that there was a case for the establishment of a uniform system of health control of international traffic in live fish and fish eggs. It was felt, however, that before implementation whatever its nature of such control, an evaluation should be made of the degree of implementation and effectiveness of existing health controls by the responsible agents as well as of the economic factors concerning present and future traffic in fish and fish eggs.

The Sixth Session of EIFAC (Krakow, 1970) followed this up by recommending that a symposium be held in 1972 which would: (*i*) review the magnitude of international exchange in live fish and fish eggs; (*ii*) study a draft code of regulations; and (*iii*) consider the practical aspects of implementation of regulatory measures.

Accordingly, a Symposium on the Major Communicable Fish Diseases in Europe and their Control, organized by FAO/EIFAC with the support of OIE, was held at Amsterdam in 1972. The meetings were technical and scientific with the participants contributing as individual scientists and not as representatives of governments or intergovernmental bodies. The Symposium had the following major objectives: (*i*) to determine the world distribution and importance of eight major communicable fish diseases; (*ii*) to determine the state of knowledge on their occurrence, etiology, diagnosis, transmission, prophylaxis and treatment; (*iii*) to determine the scientific basis for and feasibility of international control measures; and (*iv*) to develop guidelines for legislation governing control within or without international boundaries.

A background paper (Thompson, Dill and Moore, 1973) which incorporated reports from 22 EIFAC countries, the USA and the USSR, was used especially as a basis for points (*i*) and (*iv*) above. These and the other objectives, especially (*ii*) and (*iii*) dealing with scientific aspects of the problem, were reviewed by expert scientific panels. Their findings and the scientific papers presented at the Symposium as well as the report were published by EIFAC (Dill, 1972, 1973). The Symposium agreed that: (*i*) there was a need for international control; (*ii*) the most effective control method was inspection at source combined with certification; and (*iii*) aquaculture establishments under surveillance and certified free from diseases, were the ideal situation.

The Seventh Session of EIFAC (Amsterdam, 1972) accepted the scientific and technical consensus of the Symposium and requested the Director-General of FAO to consult Member Governments of EIFAC and other countries concerned to ascertain their views on an international convention for the control of international traffic in live fish and fish eggs.

Following support for this proposal a Government Consultation on an International Convention for the Control of the Spread of Major Communicable Fish Diseases was convened by FAO at Aviemore, Scotland, 30 April 1 May 1974. The great majority of the delegates recognized the need for a Convention, expressed themselves generally in agreement with the principles behind a proposed draft of such a Convention, and recommended that a revised draft be submitted to governments for further comments (FAO, 1974).

The revised draft was submitted to the Governments in mid 1975. An analysis of the replies, while generally in favour of a Convention, indicates the need for a further legal/technical Consultation.

3.3 *World Health Organization (WHO)*

The World Health Organization has also had an interest in the need for sanitary control of traffic in fish and fish products as well as that in other animal and animal products. In 1964 it met with FAO and OIE at the Meeting on Basic Principles for the Control of International Traffic of Animals and Animal Products, Berne, Switzerland, at which it was noted that fish and fish products may be the cause of transmission of infectious and parasitic diseases of man and animals, and that control of their international traffic was necessary. This complex subject may be simplified if criteria already in force for other animal products are applied to fish products (see Ghittino, 1964).

A WHO Expert Committee of Fish and Shellfish Hygiene convened in co-operation with FAO in 1973 (WHO, 1974), emphasized that fish is a nutritious protein food but that its extensive utilization raises public health problems that will increase as new resources are exploited. (The increase in aquacultural products can be included here.) Consequently their hygienic character should be guaranteed before consumption, especially to prevent some fish-borne zoonosis.

The topics discussed during this Expert Meeting were stressed at an earlier meeting organized by the American Veterinary Medical Association. Products obtained through aquaculture should be suitable for human consumption or for any domestic use, *ie*, the economic aspects of aquaculture should not take precedence over its hygienic aspects. It was pointed out that fish under extensive or intensive cultures can be much more hygienic than the fish caught in open bodies of water, inasmuch as it is possible in fish farming to control environmental conditions and thus avoid many noxious factors.

3.4 *The European Federation of Salmonid Breeders (FES)*

The Fédération Européenne de la Salmoniculture (FES), which includes representatives of the most important trout producing countries in Europe has discussed those measures already applied, or being adopted, in some European

countries for a programmed fight against dangerous communicable trout diseases such as VHS and IPN. Particular emphasis has been paid to the national campaign in Denmark to eradicate VHS and to the question of international health certificates for fish and fish eggs.

During FES Assemblies in 1974 and 1975, fears were expressed that the proposals for a draft convention for the control of fish diseases as formulated at the Government Consultation held at Aviemore in 1974 if applied strictly might interfere with the commercial trade of live fish and fish eggs. According to FES it would be highly suitable for each country to study eradication programmes for fish diseases by means of 'Specific Pathogen Free', 'Specific Disease Free' or 'Minimum Disease' methods (see section 3.1) and that an information service be established to collect data concerning fish farms registered in such manner in Europe.

4 National organizations concerned with health of aquatic organisms

The American Fisheries Society (AFS) established a Fish Disease Committee in 1964 which has influenced laws on importation of live or frozen salmonids and their eggs. They have to be certified by the country of origin to be free from *Myxosoma cerebralis* and 'Egtved virus', the etiological agents of whirling disease and VHS. The introduction and transfer of diseases of marine and estuarine fish and shellfish have already resulted in serious economic problems to commercial fisheries and mariculture in the United States, *eg*, the transfer of organisms harmful to oysters ('oyster drill' and haplosporidian, amoeboid and bacterial infections) and of crustacean diseases. Co-operation by Canadian authorities has been urged to prevent the outbreak of dangerous fish diseases in North America (Snieszko, 1968).

A Canadian Committee on Fish Diseases in 1972 emphasized that the future of Canada's aquaculture industry, its recreational fisheries, and to some extent its commercial fisheries, depended on the existence and development of sanitary fish cultural operations. Such needs were documented in a report which included an inventory on distribution of fish diseases in Canada, a review of local regulations related to fish disease control, the possibilities of managing fish diseases within the country, and the size of international traffic of live fish and fish eggs, and products from fish farms (Bell and Margolis, 1972). A Canadian manual has also been prepared concerning methods for recognizing the etiologic agents of important salmonid diseases including instructions for laboratories which must perform tests aimed at excluding fish disease agents in imported fish products (Gillespie *et al*, 1974).

Several of the countries which have the greatest interest in aquaculture are concerned about fish diseases. Different measures are taken to control them: voluntary or compulsory therapeutic treatment, a slaughter policy, and compulsory notification, with all the implicated consequences. This subject, which has been reviewed by Ghittino (1966), is reported annually in the FAO/WHO/OIE Animal Yearbook, which provides information on the incidence of fish diseases and their methods of control.

Diseases affecting ornamental fishes have not been neglected within the framework of international measures for fish health. Axelrod (1973) has reviewed the subject of control of communicable fish diseases transported by tropical aquarium fishes, and Conroy (1975) has made an evaluation of the present state of world trade in ornamental fish, which indicates the need for disease control in international traffic.

The question of preventing the diseases of aquarium fishes was thoroughly discussed at a meeting of the Pet Industry Joint Advisory Council (Ghittino, 1974). The meeting recognized the possibility of importing and spreading with aquarium fish and their transport-water, some new fish diseases, and aquatic organisms which may constitute a hazard to aquatic eco-systems. Rules were also sought for neutralizing the transport-water of ornamental fishes with chlorine compounds before disposal.

5 Legal basis for disease control in aquaculture

The comparative study of laws and regulations governing international traffic in live fish and fish eggs by Zenny (1969) (section 3.2) reviews the legal basis for international fish disease control so thoroughly that the next four paragraphs will be devoted to abridging some of the findings.

According to this paper, the majority of countries covered in the survey exercise some form of health or sanitary control over traffic in live fish and fish eggs, and have laws or regulations for it. The traffic might be prohibited, controlled or regulated concerning: the time, place and nature of health controls; the authorities performing the inspections or issuing health certificates; and eventual quarantine measures. This paper also reviewed the various methods of control existing in some countries: visual inspection of sanitary conditions of fish and transport-water, species identification, quarantine measures, packing, *etc*. The types of certificates prescribed for consignments of live fish and fish ova were described. Certificates might be issued from the country of origin, or by local inspecting authority at the points of entry; sometimes certificates were issued only if requested by the country for which the said exports were destined.

The inspecting and certifying authorities usually belong to the ministerial or governmental authority charged with regulating fishery activities, or the task is delegated to health, veterinary, or custom authorities. Quarantine measures are seldom applied and are logically restricted to observation in quarantine ponds for one day up to a maximum of 5–15 days. Some countries apply total or partial prohibitions to some or all species of fish.

The effectiveness of the measures adopted for health control exercised over the traffic of live fish and fish eggs was considered differently by the countries, ranging from being satisfactory to more or less ineffective. More collaboration in applying uniform standards of health control was sought, and the need of establishing a uniform system of health control in international traffic of live fish and fish eggs was recognized.

The implementation of a uniform system of health control and certification for this traffic might be secured through the establishment of a convention or the issue of 'norms' or 'directives' defining the methods of control and model of certificates. A convention would represent a legal binding instrument for those countries ratifying it, norms or directives would not be legally binding, but would represent standards to which countries may agree (Zenny, 1969).

As has already been related (section 3.2), steps have now been taken toward establishment of an international convention for the control of major communicable fish diseases.

In the meantime, several countries are making individual efforts to control the spread of fish diseases through legislation and regulations, *eg*, Denmark, New Zealand, UK and USA. New legislation has been introduced to control not only certain fish diseases such as VHS, furunculosis and whirling disease (Denmark Law No. 283, June 1969) but also ectoparasitic crustaceans in New Zealand (Anon., 1975) and the shellfish pests, *Crepidula, Mytilicola*, and *Urosalpinx cinerea* in the UK (Anon., 1975).

Efforts to avoid further harmful introductions and spread of diseases threatening aquaculture enterprises must be internationally co-ordinated, and they should include attention to all cultivated organisms.

6 Prevention of serious diseases of cultivated aquatic organisms

Prior to establishing addenda to the existing rules on health control in all cultivated aquatic organisms, fundamental studies must be performed concerning the identification, nature and occurrence of the principal and most dangerous pathological conditions of these cultivated organisms. Through such surveys, a decision must be reached as to which of these diseases are worthy of concentrated efforts.

Reliable and standardized diagnostic methods must also be developed to determine the basis on which health certificates can be correctly and reasonably established. The criteria for modified disease-free status and for the continuous maintenance of this status should be studied. Juvenile organisms might be exported to other aquaculture enterprises only from officially recognized disease-free aquafarms. A certification at source would be feasible if such farms were established.

First consideration should be given to those communicable fish diseases which have already been thoroughly considered by national and international organizations. Some diseases selected for their importance in causing serious losses in freshwater fish farming are VHS, IPN, infectious dropsy, furunculosis and whirling disease. Other fish diseases which are less important or still under study should be kept on a waiting list for health certificates: IHN, swim-bladder inflammation of cyprinids (SBI), channel catfish virus disease (CCVD) and pike fry rhabdovirus disease (PFRD) (Dill, 1972, 1973; FAO, 1974; OIE, 1975).

Some important diseases of cultivated marine fishes may be included in the future, *eg*, lymphocystis disease (LD), eel papilloma (EP), eel branchio-nephritis (EBN), fish vibriosis (FV), infection by acid-fast bacteria (IAFB), and certain serious parasitoses (see Ghittino, 1974; Honma, 1971). Much more must be known about diseases of marine fish before health certification can be suggested for them.

Cultivated bivalve molluscs must be protected from further introduction of serious communicable diseases that may be spread through excessive transfers. It would be suitable to prevent transfer of such oyster diseases and parasites as: those caused by bacteria ('multiple abscesses' and 'focal necrosis'); by fungi (*Dermocistidium marinum* or 'shell disease'); by amoebas; by haplosporidians (SSO by *Minchinia costalis* and MSX by *M. nelsoni*); by copepods (*Mytilicola orientalis, M. intestinalis, Pinnotheres*); and by gastropods ('oyster drill', *Urosalpinx cinerea*). Comparable action should be carried out on the prevention of some serious diseases affecting cultivated marine mussels and clams, particularly that caused by the parasitic copepod *Mytilicola intestinalis*.

Crustaceans cultivated in fresh water or sea water should be protected from important communicable diseases such as those caused by bacteria (Gaffkaemia and 'rust or shell disease' by chitinoclastic bacteria) and by fungi (*Aphanomyces astaci*).

The culture of seaweeds is affected by diseases, predators, fouling organisms, bryozoans, ascidians, amphipods and undesirable algae. No effective means for their control are known. In addition to proper management techniques, preventive measures should be undertaken, especially for seed transfers, as soon as a thorough knowledge of such pathological conditions is gained. For example, a fungus disease, caused principally by *Pythium* sp., may cause 50% losses in cultivated nori (*Porphyra*). There is also a disease whose nature is not known, causing serious losses in the cultivated seaweed *Undaria* by causing detachment of the young fronds (Bardach, Ryther and McLarney, 1972).

7 Conclusions and recommendations

Any modern aquaculture enterprise requires protection from the principal biological risks, namely the most destructive and communicable diseases of cultivated aquatic organisms. It is now time to really control the heavy losses due to infectious diseases which cause mass mortalities, through prevention rather than therapy. Otherwise, it will be difficult to manage economic aquaculture enterprises successfully.

In striving for such control, especially involving the export and import of aquatic stocks, the approach must be led by international organizations and thoroughly harmonized and co-ordinated on a worldwide basis. Otherwise, all the health programmes in aquaculture will risk failure, especially now that intensive methods are widely applied and there is a considerable transfer of stock from country to country.

Health programmes in aquaculture must be managed scientifically. Knowledge of fish diseases has progressed rapidly but primarily for diseases affecting fish cultivated in fresh water. Less is known about the diseases of marine fish which are cultivated, and even less about those of other cultivated organisms, such as molluscs, crustaceans and seaweeds. Particular studies are warranted on the subject.

The timing of these studies, may, of course, be regulated primarily by economic factors. It is logical to assume that the diseases that threaten the most valuable aquaculture stocks will be those investigated first and for which control procedures will be developed first. When the knowledge of the whole field approaches the level attained in animal husbandry and agriculture, substantial progress will have been achieved in provision of a modern, technical and scientific basis for further developments in economic aquacultures.

The products derived from such aquaculture should be guaranteed for the absence of risks of transmission of diseases or intoxications to consumers. Such assurance will improve markets and widen the scope of product use.

An attempt should be made to devise international regulations which concern the transfer of aquatic organisms destined to start or to enlarge aquaculture entities. The introduction of health certificates vouching for the absence of the major destructive diseases of aquatic organisms should be a part of this programme.

Good examples of proposed health certificates for live fish and fish eggs, concerning the absence of certain fish diseases have been already developed, *eg*, within OIE and FAO/EIFAC. Modifications of such models could be adopted for other cultivated aquatic organisms. No certificates will be perfect nor will they completely satisfy every producer, purchaser or health authority; but whatever model or models are chosen they should provide the concept of the need for certifying the health (or absence of disease) of aquatic organisms before introducing them into an aquafarm. If aquafarms are established which are officially recognized as free from the most important communicable diseases, this will further the issuance of realistic health certificates. Continued co-operation by the international organizations concerned with aquaculture will provide the means of further protection of aquaculture stocks and development of a sounder industry.

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Chapter II Finfish Culture in Ponds

Physical Problems in Fish Farm Construction

Y. A. Tang

Abstract

It is estimated that, of a total of 2·2 million ha of fish (fin fish) farms in the world, about 18% or 0·4 million ha has its water supplied by tide, and the remainder is fed by various sources of fresh water, of which approximately 85% or 1·5 million ha is principally fed by stored seepage water. These seepage water fish farms are distributed in the interior deltaic areas of the major river systems in Asia and, to a very limited extent, in the southern part of North America and in eastern Europe.

Fish farming systems using mainly natural food produce approximately 97% of the annual world fish farming production (3·7 million tons) while farming systems using artificial feed supplies constitute only about 3% of this production.

On the basis of the existing technology of tidal land development and economic structure of coastal fish farming enterprises, tide fed fish farms are generally limited to within the tidal range between the levels of mean higher high water and mean lower high water.

The low level productivity of the tide-fed fish farms in southeast Asia is attributed to soil acidity caused by the accumulation of iron sulphides in the subsoil. Provision of adequate drainage facilities for improving these acidic soils by leaching is an absolute necessity.

Selection of a seepage water pond site depends largely upon the degree of water resources development in the delta and the degree of flood control in the river system. Information about hydrological features of the area would furnish basic data for evaluating the suitability of a farm site and for the planning of farm construction. Installation of drainage facilities for a seepage water type fish farm is expensive, but it is one of the basic requirements for intensifying fish production for this type of pond. Most of the existing seepage water fish ponds in Asia are small and shallow for practising the traditional Chinese fish farming system. For intensifying fish farm management, land consolidation may be necessary.

Loss of water through seepage is a problem that faces many rain-fed and diverted and ground water fish farms. Effective measures for minimizing seepage flow, engineering design and proper construction of these types of fish farms are essential.

Fish farming in pens and in other types of enclosures constructed in coastal and lake waters is expected to develop rapidly in the future.

La construction de fermes aquicoles—problèmes materiels

Resumé

L'on estime que sur 2·2 millions d'hectares d'aires aquatiques utilisés par les fermes piscicoles (production de poisson proprement dit), quelque 18% soit 0·4 million d'hectares, sont tributaires des marées, les autres surfaces étant alimentées par diverses sources d'eau douce dont 85% du total, soit 1,5 millions d'hectares, sont essentiellement tributaires de l'accumulation des eaux d'infiltration. Ces fermes piscicoles alimentées par des eaux d'infiltration sont disséminées dans les zones deltaïques intérieures des grands systèmes fluviaux de l'Asie, et dans une mesure très limitée dans la partie méridionale de l'Amérique du Nord et en Europe orientale.

Les systèmes piscicoles fondés sur l'utilisation d'aliments naturels procurent quelque 97% de la production annuelle mondiale de poissons d'élevage (3,7 millions de tonnes), alors que le système de pisciculture utilisant des aliments artificiels ne fournit qu'environ 3% de cette production.

Sur la base de la technologie actuelle de mise en valeur de la zone de balancement des marées et de la structure économique des entreprises de pisciculture côtière, les fermes piscicoles tributaires des marées sont généralement limitées aux zones de marnage comprises entre la laisse de haute mer moyenne et la laisse de basse mer moyenne.

Le faible taux de productivité des fermes piscicoles tributaires des marées en Asie du sud est est attribué à l'acidité du sol, elle même imputable à l'accumulation de sulphides de fer dans le sous sol. Il est absolument nécessaire d'aménager des installations de drainage adéquates pour améliorer ces sols acides par le lessivage.

Le choix du site d'un étang alimenté par des eaux d'infiltration dépend largement de la mise en valeur des ressources hydrauliques dans le delta et de la maîtrise des crues dans le système fluvial. Des renseignements sur les caractéristiques hydrologiques de la région fourniraient des données de base permettant de déterminer si un site convient à la pisciculture et de planifier la construction de l'exploitation. L'installation de systèmes de drainage pour une ferme piscicole alimentée par des eaux d'infiltration est coûteuse, mais elle constitue l'une des exigences fondamentales de l'accroissement de la production de poisson dans ce type d'étang. La plupart des étangs de pisciculture conçus sur ce modèle en Asie sont petits et peu profonds afin d'y pratiquer la pisciculture chinoise traditionnelle. Pour intensifier l'aménagement des fermes piscicoles, il peut être nécessaire de consolider les sols destinés à ces exploitations.

Les pertes par infiltration constituent un problème auquel se heurtent nombre de fermes piscicoles alimentées par des eaux de pluie, des eaux de dérivation et des eaux souterraines. Il est indispensable de prendre des mesures efficaces pour minimiser ces infiltrations lors de la conception et de la construction de ce type d'exploitation.

L'on pense que la pisciculture en parc et dans d'autres types d'enclos construits dans les eaux côtières et lacustres se développera rapidement.

Problemas materiales de la construcción de explotaciones piscícolas

Extracto

Se calcula que del total de 2,2 millones de hectáreas en que se estima la superficie dedicada al cultivo de peces en todo el mundo, el 18% o sea 0,4 millones de hectáreas, se abastecen con agua de las mareas, mientras en el resto se utiliza agua dulce de diversas procedencias, de las cuales el 85% de la superficie o sea, 1,5 millones de hectáreas, se alimentan mediante embalse de aguas procedentes de infiltraciones.

Estas granjas piscícolas en aguas procedentes de infiltraciones están distribuidas en las zonas deltaicas interiores de los principales sistemas fluviales de Asia y, en proporción muy limitada, en la parte meridional de América del Norte y en Europa oriental.

El sistema de granjas piscícolas basado en el empleo de alimentos naturales produce aproximadamente el 97% de la producción piscícola mundial anual (3,7 millones de toneladas) mientras el sistema de cultivo con empleo de piensos artificiales representa solo el 3% de esta producción.

Dada la tecnología actual existente para el desarrollo de zonas de marisma y la estructura económica de las granjas piscícolas costeras empresariales, el emplazamiento de las granjas piscícolas alimentadas por las mareas se limita generalmente a las zonas entre la media superior de la marea alta y la media inferior de la marea alta.

La escasa productividad de las granjas piscícolas alimentadas por agua de las mareas en el sudeste de Asia se atribuye a la acidez del suelo, causada por la acumulación de sulfatos de hierro en el subsuelo. Es absolutamente necesario construir instalaciones adecuadas de drenaje para mejorar esos suelos ácidos mediante lixiviación.

La selección de emplazamiento de un estanque de aguas procedentes de infiltraciones depende en buena parte del grado de desarrollo de los recursos hídricos en el delta y del control de las inundaciones en el sistema fluvial. La información sobre las características hidrológicas de la zona ofrecerá datos básicos para evaluar la conveniencia de un lugar dado y planificar la construcción de las instalaciones. En las granjas piscícolas en las que se utilizan aguas procedentes de infiltraciones la construcción de sistemas de drenaje es costosa, pero representa uno de los requisitos básicos para intensificar la producción en este tipo de estanques. La mayor parte de los estanques piscícolas existentes en Asia son pequeños y poco profundos para practicar en ellos el sistema piscícola chino tradicional. Para intensificar el manejo de la granja piscícola puede ser necesario proceder a una consolidación de terreno.

La pérdida de agua por infiltración constituye un problema en muchas granjas piscícolas alimentadas con aguas de lluvia, derivadas de cursos de agua o subterráneas. Es esencial tomar medidas eficaces para reducir al mínimo esas pérdidas y planear y construir adecuadamente las instalaciones.

Se espera que el cultivo de peces en recintos y otros tipos de cercados en aguas costeras y lacustres se desarrolle rapidamente en un futuro cercano.

1 Introduction

Aquaculture is receiving worldwide interest, and the development of this food production industry has been substantial in recent years. This includes, for example, the great increase of Asiatic carp farming in China, the rapid growth of catfish farming in the USA and Thailand, and yellowtail (Carangidae) farming in Japan. A great increase in fish (finfish) farming production is envisaged as a result of intensification of production from existing fish farms and the expansion of areas under cultivation.

This paper examines the various kinds of fish farms, and reviews the major physical problems facing their

construction and the priorities for their solution if rapid development of this industry is to be achieved.

2 Classification of fish farm types, farming systems and management intensity

2.1 *Types of fish farms*

The types of fish farm now in use can be categorized on the basis of: (*i*) the environmental characteristics of the land and water; (*ii*) nature of physical structures, and (*iii*) the particular fish which is used, specified by species, species-groups, or by their growing stages (Table I).

Since water is essential to fish life, and water control structures constitute the bulk of construction costs, classification of fish farm types based on their sources of water would be useful.

Of the estimated 2·2 million ha of world fish farm area (Pillay, 1973), approximately 18% or 400 000 ha comprises tide-fed fish farms; the remainder includes fish farms fed by the collection of surface water run-off, storage of seepage or spring water, diversion of flow from rivers, streams or irrigation canals and, to a limited extent, the pumping of ground water. In practice, water supply to a fish farm may combine two or more of these water sources. Statistics on the area of these types of farms are not available, but it is estimated that there are about 40 000 ha of rain-fed farm ponds in the USA, approximately 1.5 million ha of seepage-water type fish farms distributed in the interior deltaic areas of the major river systems in China, India and Bangladesh, and appreciable areas of diverted-water type farms for trout culture and of ground-water type farms for raising eel.

TABLE I
CATEGORIES OF FISH FARM TYPE

Classified on the basis of:	*Fish farm type*
Characteristics of the farm environment	
Water temperature	Warm water
	Cold-water
Water salinity	Fresh-water
	Brackish water
	Salt-water
Land topography	Upland
	Lowland
	Terraced
Water movement	Running-water
	Standing water
Sources of water	Rain-fed
	Tide fed
	Diverted-water
	Seepage water
	Ground water
	Spring-water
Physiographical zones	Inland fish farm
	Coastal fish farm
	Marine fish farm
Characteristics of the physical structure	
Nature of enclosures	Pond fish farm
	Cage fish farm
	Pen fish farm
	Raceways
Kind of materials used for enclosures	Plastic tank
	Concrete tank
	Earth pond
Particular kind of cultured fish	
By species or a group of species	Catfish farm
	Carp farm
	Tilapia farm
	Mullet farm
By certain growing stages of the species	Milkfish nursery farm
	Carp breeding farm (carp hatchery)
	Trout hatching farm (trout hatchery)

2.2 *Systems of fish farming*

Fish farming systems can be classified on the basis of fish farm management techniques and procedures which would involve: (*i*) management of a fish population or populations; (*ii*) feeds and feeding of fish; and (*iii*) unique procedures or techniques that have been developed for a species or group of species, a combination of fish and other farm crops or livestock, or certain levels of management intensity of a farming system (Table II). Since feed is vital for regulation of fish growth and constitutes the bulk of farm input cost, classification of fish farming systems based on their sources of food supply would be relevant and meaningful.

Of the estimated 3·7 million tons of world fish farming production (Pillay, *op. cit*), only 3% or less (about 100 000 tons) is produced by farming systems based on artificial feed supply, compared with the remaining production based on the supply of natural foods. Except in running water fish farms, the growth of natural fish-food organisms also plays an important role in the farming system based on artificial feed supply. This is evidenced by the fact that proper growth of blue-green algae creates a more favourable environment for eel culture (Usui, 1974) and the production of bottom organisms provides nutritive foods to meet the dietary requirement of common carp and catfish reared in ponds with intensive feeding.

TABLE II
CATEGORIES OF FISH FARMING SYSTEMS

Classified on the basis of:	*Fish farming system*
Characteristics of fish population management procedures and techniques	
Stocking, by number of species	Mono-species fish farming (monoculture)
	Multi species fish farming (polyculture or mixed culture)
Stocking, by size group of species	Single-size stocking
	Multi size stocking
Harvesting, by number of croppings	Single cropping
	Multiple cropping
Characteristics of feeds and feeding of fish	
Sources of food supply	Based on a natural food production system
	Based on an artificial feed supply system
Kind of natural foods	Based on a benthic algal production system
	Based on a planktonic algal production system
	Based on a filamentous green algal production system
Usage of artificial food	Based on a balanced feed system
	Based on supplemental feeding
Unique management procedures or techniques	
For a species or a group of species	Asiatic carp farming
	Bluegill and bass farming
	Eel farming
	Trout farming
For a combination of other farming crops	Prawn and milkfish farming
	Rice and fish farming
	Duck-cum-fish farming
For the levels of management intensity of a farming system	Extensive fish farming
	Semi-intensive fish farming
	Intensive fish farming

2.3 *Intensity of fish farm management*

The intensity of fish farm management on the basis of a natural food production system can be grouped into four levels which are given in Table III. A prerequisite for determining the level of management intensity of a fish farm is the quantity and quality of available pond water which could be provided by the construction of adequate water control structures in suitable farm sites.

Fish production has recently been intensified by Chinese fish farmers through implementation of five improvements in fish farm construction: (*i*) deepening of the pond, (*ii*) enlargement of pond size, (*iii*) provision of drainage, (*iv*) prevention of leakage and (*v*) construction of lake water enclosures. These measures have resulted in a significant increase in the national average of fish farming production (China Fresh-Water Fish Culture Experiences Summing up Committee, CFFCESC, 1961).

3 Tidal fish farms

3.1 *Limitations in site selection*

It is estimated that about 10 million ha of tidal lands are distributed in tropical regions in Asia (Pillay, *op. cit.*). The present tidal land reclamation for use in fish farm development is limited to those areas situated at the tidal range between the levels of mean higher high water (mean high water level at spring tide) and mean lower high water (mean high water level at neap tide). Ground levels of tidal lands that are higher than mean higher high water tide level are usually used for agriculture, such as the planting of tree crops (palm oil and coconut) or short root crops (rice, vegetables, *etc*) and, to some extent, short root crops and fish/shrimp in rotation. Due to basic differences in environmental requirements for operation of these two types of farming, this pattern of tidal land use is expected to continue for some time in the future despite the increase in land demand for coastal fish farming development.

Limiting of tidal land reclamation to ground levels beyond the mean lower high water (mean high water level at neap tide) are the technical difficulties associated with (*i*) constructing large earth embankments and heavy concrete structures on soft ground or a low bearing capacity foundation, and (*ii*) providing adequate drainage facilities for pond soil improvement and leaching (see Section 3.2). Unless there is a significant breakthrough in the technology of tidal land development or a drastic increase of earnings in coastal fish farming business, it is unlikely that these limitations will be removed in the near future.

3.2 *Drainage*

Drainage is the disposal of pond water as required by the procedures of fish farm management. Excessive water from any source of supply may directly cause damage to fish farm facilities and loss of fish crops, and indirectly affect pond productivity by creating unfavourable environments for aquatic life (such as the development of soil acidity, change of water salinity, *etc*).

Coastal clay soils are generally highly acidic. This is caused mainly by: (*i*) presence in the subsoil of hydralite, a type of black, fine-grained sulphate deposit in water-logged estuarine sediments (Berner, 1967), and (*ii*) the decomposition of mangrove roots under anaerobic conditions. This type of soil acidity reduces the pH value to 3–5, an unfavourable level for the growth of aquatic organisms.

Of a total of 170 000 ha of coastal fish farms in the Philippines, approximately 60% or 100 000 ha are affected by soil acidity (Tang, 1973). Ponds with this type of soil produce only a few hundred kilogrammes of fish per hectare annually. Unless the soil acidity is corrected, productivity of these ponds cannot be improved. Field experience shows that soil acidity caused by the decomposition of mangrove roots under anaerobic conditions can be improved by heavy application of lime (Padlan, 1964). However, the improvement of soil acidity caused by the accumulation of iron and sulphide salts requires their removal by leaching, a process which involves removal of these undesirable salts from the subsoil by percolating the tidal flow through a series of interceptor drains.

TABLE III

LEVEL OF MANAGEMENT INTENSITY FOR THE FISH FARMING SYSTEM BASED ON NATURAL FOOD PRODUCTION

Level of management intensity	*Characteristics of farm management*	*Level of standing crop of fish food organisms (kg/ha)*[2]	*Level of standing crop of fish (kg/ha)*[1]	*Remarks*
0	Without management (either for fish population or for fish food supply)	1 200	140	Both the fish population and water fertility of the impoundment are uncontrollable
I	The stocked fish are supported by the fish food organisms produced only by natural productivity	1 200	420	Fish population of the impoundment is manageable but the water fertility is uncontrollable
II	The stocked fish are supported by: (*i*) natural productivity of the bodies of water, plus (*ii*) the increased productivity by fertilization which is approximately 500% more than natural productivity	7 200	2 500	To a large extent both the fish population and water fertility of the impoundment are controllable
III	The stocked fish are supported by: (*i*) natural productivity, (*ii*) the increased productivity by fertilization, and (*iii*) supplemental feed, the additive factor of which can increase the conversion rate of natural food to fish production by 200%; or raise fish production threefold above the II level of management intensity	7 200	7 500	Both the fish population and water fertility of the impoundment are completely controllable

[1] Refer to Tang, 1970.

[2] Wet weight. Figures as indicated are under tropical and subtropical conditions and the sizes, depths and other environments of impoundment are similar to those of ordinary fish farms.

The type of drainage facility required for this purpose is a system of open canals along the natural waterways in the pond site. The depths of these canals should approach the tidal level of mean lower low water. This is to allow removal of the maximum amount of percolated tidal flow over the permeable stratum, whose level fluctuates with the tidal level. In the process of leaching, the water level in the drainage canals should be kept constantly at a minimum of 30–40 cm lower than the ground level. The time required for leaching varies mainly with the amount of salt accumulation, volume and frequency of percolating tidal flow, soil permeability, climatic conditions, *etc.* In general, the pH value of this type of acid soil will be raised to a satisfactory level within two to three years.

3.3 *Size and depth of pond*

The size and depth of a pond affect the efficiency of land and water utilization and influence the environments of the pond which, in turn, govern the pond productivity and its fish-carrying capacity. Different fish farming systems under a certain level of management intensity require different sizes and depths of pond. Chinese fish farmers say that, 'the more extensive the water body is, the larger the growth of the fish' and also 'an increase of one inch of pond water increases the growth of the fish by one inch' (CFFCESC, *op. cit.*). This means that, in general, under the Chinese fish farming system, a larger and deeper pond gives high fish production. This has also been proved to be true with tilapia farming in many other areas.

The size of individual ponds of tide-fed fish farms in Indonesia, the Phillipines and Taiwan Province of China, as indicated in Table IV, is determined by a combination of technical, economic and social factors. In general, the larger the pond size, the greater is the efficiency of land and water utilization and the lower the construction costs; on the other hand, the smaller the pond size, the more convenience of pond management and the lower the earth work maintenance costs. The most suitable size of individual pond for a tide-fed fish farm operation can be determined on the basis of a comprehensive evaluation of technical, economic and social aspects in fish farm construction, maintenance and operation. For the intensification of production and future expansion of this type of fish farm in the Philippines, the size of individual pond should be altered to meet the requirements of intensive management and to reduce the cost of maintaining earthworks damaged by wave action. In Indonesia, on the other hand, fish farm land consolidation may be required because the physical improvements necessary to intensify production from such small-sized ponds may not be technically and economically feasible, particularly because of the limitation in tidal water supply.

TABLE IV
SIZE OF TIDE-FED FISH PONDS IN THE PHILIPPINES, INDONESIA AND TAIWAN PROVINCE OF CHINA

Country	*Size*	
	Range (ha)	*Predominant size (ha)*
Philippines	3·0 25·0	10·0–15 0
Indonesia	0·1– 5·0	0·3– 1·0
Taiwan Province of China	1·0– 7·0	4·0– 6·0

The water level of a tide-fed fish pond is principally determined by both technical and economic factors which involve: ground elevation, tidal range, bearing capacity of embankment foundation and economic benefits derived from this type of fish farming operation. With the existing technology and economic structures of this type of fish farming business, the increase in water level of individual ponds that can be provided is limited to 30 60 cm. Chinese fish farmers in Taiwan Province, who have the benefit of generations of experience, have been able to substantially raise fish production from this type of fish farm by intensifying the production of microbenthic algae which grow well in shallow water and which serve as good food for milkfish (*Chanos chanos*), and by proper manipulation of the pond fish population, despite the fact that climatic conditions are unfavourable for the growth of microbenthic algae and milkfish (Chen, 1951). There is no doubt that if it were technically feasible to increase the water level of these ponds so that it approached the level of Chinese carp ponds (about 2 3 m deep) it is conceivable that fish production could be raised to that of traditional carp ponds (about 6–9 tons per annum). It appears, however, that unless there is a significant breakthrough in the technology of tidal land development and/or a drastic change in the economic structures of tide-fed fish farm business, this type of fish pond still has to be constructed with a limited depth of pond water.

4 Seepage-water fish farm

4.1 *Limitations in site selection*

Seepage-water type fish farms are usually distributed in the depression areas of an interior delta. The water levels of the river system regulate the water table fluctuation in deltaic areas which, in turn, control the quantity of pond water. The suitability of the site for this type of fish farm depends largely upon the water resource development in the area and flood control measures in the river systems. Without integrated water resource development, this type of fish farm development faces many technical and economic difficulties in constructing the necessary water control structures.

In areas where a seepage-water fish farm is to be sited, it is essential to review the hydrological aspects of water development in order to assess the amount of water that could be made available and to obtain basic data to be used in planning, designing and constructing the structures required for water control. Data required include: river discharge, water table fluctuation, soil permeability, land gradient, rainfall and rainfall distribution, evapotranspiration *etc.*

4.2 Drainage

The drainage problems in this type of fish farm are accelerated by the year-round impoundment of water. Pond productivity in an undrainable pond would be reduced because the continuing decomposition of accumulated organic matters lowers the soil pH and develops an unfavourable environment for growing fish food organisms and the fish. In many instances it also induces the growth of fungi which attack unhealthy fish. This is especially true for old ponds and pond soils with a heavier texture.

Since the water level of this type of pond is regulated principally by the water table fluctuation in the area,

installation of gravity drainage facilities in this type of fish farm is usually difficult because of the involvement of a high construction cost of water control structures. This is especially true in the areas where the water resources have not been properly developed. Drainage by pumping is possible, but will depend on the economic situation.

4.3 *Size and depth of pond*

The size distribution of this type of pond is not known. In general, where water resources of the area have been well developed for a long period of time, the size of this type of pond is relatively small, say, usually, less than 0·5 ha. This is mainly because of generations of land inheritance. There are hundreds of thousands of these ponds that are distrib uted in the interior deltaic areas in the Yangtze River system in China and possibly in some major river systems in India and Bangladesh. A fish farm land consolidation programme has been implemented for some years in China. The main aim of this programme is to combine a number of small sized ponds to form a manageable size of 0·5–1·0 ha, sometimes of 5–30 ha, depending on the physical features of the land and the requirements of water supply and drainage facilities of the pond. It has been found that, excepting some inconvenience in pond operations (such as the harvest of fish), fish production in the Chinese fish farming system from a larger pond (ranging from 5 to 30 ha) is comparable to that of smaller ponds (ranging from 0·5 to 1·0 ha) (CFFCFSC, *op cit.*).

The Chinese carp ponds can generally be grouped into three categories on the basis of pond depth and level of production (Table V). Although most fish ponds with high production have a depth of 3–4 m, it is suggested on the basis of dissolved oxygen distribution that small ponds of less than 0·5 ha should generally not have a depth of more than 3·0 m (CFFCESC, *op. cit.*).

TABLE V
GROUPING OF CHINESE CARP FARMING PONDS BASED ON WATER DEPTH AND LEVEL OF FISH PRODUCTION

Water depth (m)	*Level of fish production (kg/ha/year)*	*Remarks*
1·2–2·0	< 7 500	Most of the ponds had this depth before the start of the fish farm land consolidation programme. There are still extensive areas of ponds with this depth
2·0–3·0	7 500 approx	Most of the ponds have this depth after the fish farm lands were consolidated.
3·0–4·0	>7 500	Most of the high production ponds belong to this depth category

Data from CFFCESC, 1961

5 Other types of fish farm

5.1 *Diverted water fish farm*

Excepting for the flow released from large reservoirs, water diverted from a stream or creek is usually not constant in its supply. This is especially true in tropical and sub-tropical regions where rainfall and rainfall distribution are extremely uneven and where water resources have not been properly developed. Water pollution due particularly to contamination by pesticides poses serious problems for the expansion of this type of fish farm and challenges fish culturists to find an adequate solution.

In the type of fish farming where disease prevention is of decided importance (*eg* trout farming), the use of water diverted from streams or lakes containing disease-bearing populations of wild fish is also inadvisable. In such cases, spring or even well water is usually substituted.

5.2 *Rain fed fish farm*

A serious problem encountered in the construction of this type of fish pond is the difficulty of installing an adequate water spillway. Inadequacy of the spillway causes the loss of water fertility, escape of fishstock and, sometimes, the collapse of earth embankments. The major factors that affect the capacity of a spillway are the rainfall and rainfall distribution, water permeability of the soils, area and topography of the watersheds, type and density of vegetation, evapo-transpiration, *etc*. Except for some information relating to southern USA (Lawrence, 1949) little is known about these aspects.

5.3 *Ground-water fish farm*

Most of the modern eel farms are supplied with pumped ground water. The recent energy crisis has greatly affected the economic structure of the operation of this type of fish farm.

Some trout farms where control of disease is very important also use ground water. An important consideration here is the even temperature that may be required.

5.4 *Spring-water fish farm*

Many large trout farms (*eg* those in the western United States) use spring water. Relatively constant temperature, uniformity in flow and chemical content, lack of silt, and absence of pollutants and disease organisms are the principal reasons for their use for salmonid species.

Water loss through seepage from fish ponds poses a serious problem in fish farm management. The amount of seepage flow from a body of impounded water varies greatly with the permeability of pond soils at various strata and of embankment materials, size, shape and compactness of embankment, as well as the fluctuations of water table under the pond bottoms and of water level of the pond. Engineering design and proper construction of these types of fish pond are of paramount importance in minimizing the large loss of water through seepage.

6 Construction of pens and other types of enclosures in natural bodies of water

The construction of enclosures with bamboo screens in lakes was initiated in Checkiang, China in the eighteen forties. Now there are approximately 0·9 million ha, or 28% of the potential area being used for this type of fish farm in China. Average fish production from these bodies of water is still low, approximately 250 kg/ha per annum. With massive production of synthetic fibres for twine and net, such as nylon, vinylon, polyethylene, *etc*, which are durable materials for use in the construction of enclosures, farming of fish in net enclosures constructed in coastal and lake waters is expected to be rapidly expanded. This can be evidenced in the Philippines where the culture of milkfish in lake water enclosures has been very rapidly developed in recent years (Delmendo and Gedney, 1974). There are millions of hectares of eutrophic lakes and lagoons

distributed in tropical and subtropical regions in Asia, Africa and Latin America, and a rapid expansion of this type of fish farm is expected to occur in the future.

The success of this type of fish farming depends largely on site selection. In eutrophic lake water with high primary production, where phytoplankton and plankton produced scum are accumulated, there are usually good sites for setting up fish pens or enclosures. Factors that cause plankton accumulation are: (*i*) prevailing direction and velocity of water currents, (*ii*) shape of water basin, and (*iii*) topography of the shorelines (Tang, 1972). Major problems facing the development of this type of fish farming are water pollution and the conflicts with other uses of the lake such as navigation and recreation.

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Planning, Design and Construction of a Coastal Milkfish Farm

Y. A. Tang

Abstract

The present approach and guiding principles related to planning, design, construction and criteria for site selection of milkfish (*Chanos chanos*) tide fed fish farms are described. Emphasis is placed on the requirements for water control structures, physical features of potential farm sites, and regional climatic conditions.

In selecting suitable sites for tidal fish farms, consideration should be given to: ground elevation and tidal ranges, soil type, type and density of vegetation, stability of banks, vulnerability to flooding, physical obstructions (rocks, mounds) and social and economic factors. Other important factors include the pond management system to be used, pond environment and weather.

Information is provided on the general layout and typical design of a tide fed fish farm.

Planification, conception et construction d'une exploitation piscicole cotière pour le milkfish

Résumé

Le document expose la methode et les principes directeurs suivis actuellement pour la planification, la conception, la construction et le choix du site des exploitations d'elevage de milkfish (*Chanos chanos*) tributaires des marees. L'on examine en particulier l'amenagement de l'écoulement, les caractères physiques des sites potentiels d'exploitation piscicole et les conditions climatiques régionales.

En choisissant des sites convenant aux exploitations piscicoles tributaires des marées, l'on tiendra compte des considerations ci-après: altitude et amplitude des marées, type de sol, type et densité de la végétation, stabilité des berges, vulnérabilité aux crues, obstacles matériels (rochers, monticules) et facteurs sociaux et économiques. Parmi d'autres facteurs importants figurent le système d'amenagement des étangs à utiliser, l'environnement et le climat.

Des informations sont données sur l'implantation generale et la conception typique d'une ferme piscicole côtière.

Planificación, diseño y construcción de una granja costera de sabalotes

Extracto

Se describe el enfoque actual y principios fundamentales de la planificación, diseño y construccion de emplazamientos piscícolas alimentados con agua de las mareas para la cria de sabalote (*Chanos chanos*), así como los criterios para la elección del emplazamiento. Se insiste en la necesidad de estructuras para el control del agua, en las caracteristicas físicas de los emplazamientos potenciales, y en las condiciones climáticas regionales.

A la hora de elegir un lugar adecuado para la instalacion de emplazamientos piscícolas alimentados por las mareas, ha de tenerse en cuenta: elevación del terreno y rango de las mareas, tipo del suelo, tipo y densidad de la vegetación, estabilidad de las costas, vulnerabilidad a las inundaciones, obstáculos físicos (rocas, terraplenes), y factores sociales y economicos. Otros factores importantes son el sistema de manejo de los estanques que ha de utilizarse, el medio ambiente de los estanques y el clima.

Se provee informacion sobre la disposicion general y diseño tipico de una granja piscicola alimentada con agua de las mareas.

1 Introduction

Planning, design and construction of a fish farm depends upon the type of farm as well as the system of farming. For each farm type within a farming system, consideration should be given to: (*i*) the physical features of the land, such as the properties of the soils, quantity and quality of available water and topography; (*ii*) the climatic conditions of the region, such as temperature, sunshine, rainfall, evapo-transpiration and hazards; (*iii*) availability and cost of construction equipment and materials, and transportation and communication facilities; and (*iv*) social factors, such as the quantity and quality of available manpower, and conventions and customs.

Basically, fish farm planning, design and construction require wide knowledge and experience of fish farm development and management. It is also essential to have a basic knowledge of hydrology, hydraulics, civil engineering, mechanics, soil science, farm economics, *etc.* Kato (1975) has given some guidance on the application of engineering planning, design and construction of coastal fish farms and described the basic engineering techniques required for the design and construction of their physical structures.

The modern approach in fish farm planning is to obtain the services of: (*i*) aquaculturists to evaluate the technical feasibility of developing major types of fish farms and quantify the input requirements for fish farming systems under different levels of management intensity for the potential sites to be developed; (*ii*) engineers to assess the available sources of water supply and ascertain the techniques of development and estimate the development cost; and (*iii*) experts of farm management to analyse the proper combination and operation of production factors, including land, water, labour and capital and suggest an optimal farm management practice for higher production efficiency and

maximum farm earning. The combination of such expertise should ensure development of a viable fish farm and farming system.

2 Criteria for site selection

The criteria for site selection for a coastal fish farm are conditions and requirements for the environment of a proposed tidal-land area that are technically and socio economically suited to the construction of necessary structures and facilities. These should, at the same time, be favourable for the farming of milkfish (*Chanos chanos*) and possibly of other species in that type of farm.

2.1 *Requirements for farm construction*

2.1.1 *Ground elevation and tidal range.* The ground elevations of a tide fed fish farm approximate the tidal levels of mean lower high water or of mean high water at neap tide. The deviation from this tidal level depends upon the range of tide (Table I). In general, where the range of tide is small, for example 1·2 m, the ground elevations of the farm site would be within the range between the mean tidal level and the level of mean high water at neap tide and where the tidal range is large, for example 2·5 m, the ground elevations would fall between the levels of mean high water at spring tide and neap tide. Tidal swamplands with a ground level out of the limits between the mean tidal level and the level of mean high water at spring tide, are usually impractical to reclaim for this type of fish farm development because of their associated technical and economic difficulties.

2.1.2 *Soil type.* The structural characteristics and textural grades of the soils determine the bearing capacity of the foundation and stability of the embankments and also affect the cost of earth work in farm construction

The textures of the alluvial soils in deltaic areas are generally heavy, ranging from sandy loam to heavy clay (Tang and Chen, 1967). Soils of this type have good water retention properties but are very soft and difficult for use in constructing earth embankments. Moreover, these alluvia extending to approximately 2·0 m below the top soil usually have a very weak structure They are characterized by a low bulk density, high liquid limit, and high plasticity (Table II). With saturated moisture, soils of this type result in poor ground and low bearing capacity of embankment foundation.

It is advisable that sand and silt, which can usually be found in layers along the seashore and the banks of major river systems be used for the foundation soil to stabilize the foundation of embankments. This is especially important for large scale coastal fish farm development.

TABLE II
PROPERTIES OF TYPICAL SOIL DISTRIBUTED ALONG TROPICAL TIDAL SWAMPLANDS[1]

Profile (cm)	*Moisture content (%)*	*Bulk density (g cm^{-3})*	*Unconfined compression (g cm^{-2})*
0–30	115	1·4	145
30–60	80	1·3	120
60–90	110	1·3	120

[1] Samples from a fish farm on Luzon Island, the Philippines

2.1.3 *Type and density of vegetation* Land clearing of tropical rain forests is time consuming and expensive. The type and density of vegetation, and the size, wood density and root system of individual trees greatly affect the methods of clearing and the procedures of farm development and development cost. Distribution of typical vegetations in tropical tidal swamps depends principally on the land elevation, soil type, and water salinity and current General characteristics and distribution of major types of vegetation relevant to land clearing are given in Table III.

2.1.4 *Other requirements.* (*i*) Stability of shore and banks: Perimeter dikes at the seashore or river bank which are subject to erosion require strong footings and slope protection. Sediment along the shore or the bank may affect the future water supply and drainage of the fish farm.

(*ii*) Vulnerability of flooding: Fish farms sited in a region where there is frequent destruction by flood involve substantial cost for the construction of large water-control structures and subsequently higher maintenance cost.

(*iii*) River and tributaries: In areas where there are too many small rivers and distributaries, more dikes and other water control facilities have to be provided. Consequently, the construction cost will be high.

(*iv*) Mounds, rocks and other impediments: Any impediment to construction work in the area will result in an increase of cost and prolonged construction time

(*v*) Social and economic factors: Considerations should be given to the availability of construction materials, accessibility of the area, facilities for transport of heavy equipment, availability of skilled and unskilled labourers, *etc.* Laws and regulations pertaining to the use of swamplands should also be reviewed and consultations held with the agencies concerned

2.2 *Requirements for farm management*

2.2.1 *Pond environments.* Water temperature required for brackishwater fish farms ranges from 25–33°C The water

TABLE I
GROUND ELEVATIONS OF A TIDE FED FISH FARM IN RELATION TO TIDAL RANGES

Ground elevation	*Tidal range*	*Distribution of fish farm area*
0·0–0·2 m below the level of mean lower high water (or of mean high water at neap tide)	1·0–1·2 m	The northern coast of West Java, Indonesia and the west coast of Central Luzon, the Philippines
Approximate to the level of mean lower high water (or of mean high water at neap tide)	1·2–2·0 m	The coasts of Panay and Negros, the Philippines and the southwestern coast of Taiwan Province of China
0·0–0·6 m above the level of mean lower high water (or of mean high water at neap tide)	2·0–3·0 m	The coast of Zamboanga, the Philippines, and the northeastern coast of East Java, Indonesia

TABLE III
GENERAL CHARACTERISTICS AND DISTRIBUTION OF MAJOR TYPES OF VEGETATION IN TYPICAL TIDAL SWAMPS

Type	*Characteristic*			*Distribution*		
	Hardness of wood	*Root system*	*Size (cm in diam.)*	*Elevation*	*Salinity (ppt)*	*Soil type*
Rhizophora	moderate	lateral	30–100	Between the levels of MTL[1] and MHHW[2]	10–35	silt and clay
Avicennia	hard	lateral	10–70	above the level of MLHW[3]	5–30	silt and clay
Nipa	soft	lateral	10–30	above the level of MHHW	0–20	sandy loam and silt

[1] MTL: mean tide level [2] MHHW: mean higher high water. [3] MLHW: mean lower high water

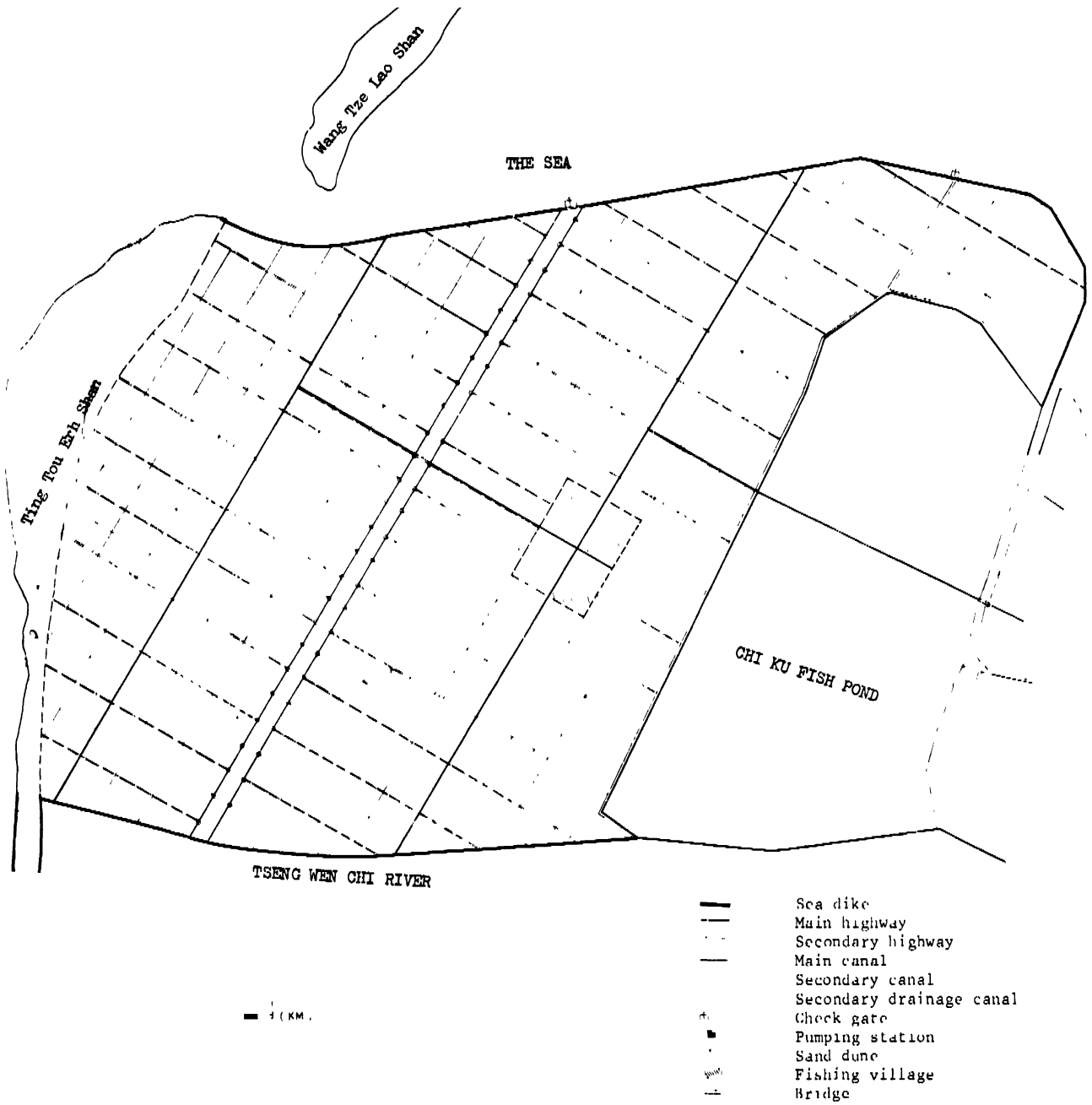


Fig 1. General layout of a 1 600 ha newly reclaimed fish farm site

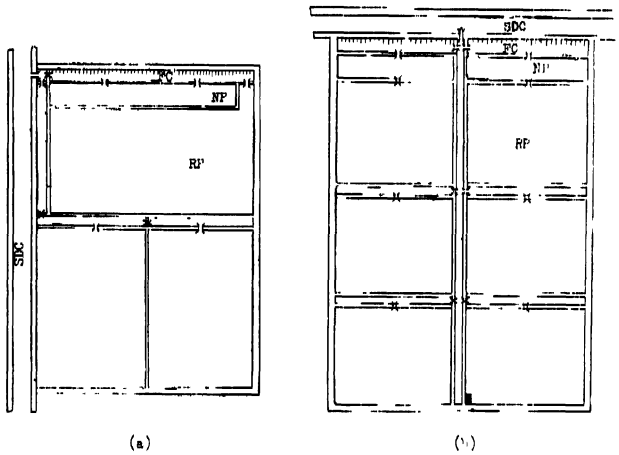


Fig. 2. The layout of a 10 ha farm unit (a) and a 30 ha farm unit (b)

level and salinity requirements upon which the growth of different groups of algae depends are given in Table IV.

Soil properties, particularly fertility, structure and texture, directly affect the growth of different groups of algae. In general, soils with a heavy texture and rich in organic matter are favourable for the production of filamentous blue-green algae, which is one of the most important fish food crops for tide-fed fish farms (Tang and Hwang, 1967).

2.2.2 *Pond water management.* In general, farms with a higher ground elevation (on the basis of datum level) but within the limits described in section 2.1.1, will have the advantage of better water drainage; whereas those with a lower ground elevation will be more conveniently situated in relation to the water supply. The convenience of pond water management will depend on the farm drainage. In other words, farms situated in an area with excessive rainfall and water-logged subsoil would require a higher ground elevation than those having no drainage problem.

2.2.3 *Other requirements.* (*i*) Weather: The amount and intensity of sunshine, rainfall and its distribution, and the evaporation rate directly and indirectly influence the growth of fish food organisms which, in turn, affect fish production. Typhoons and floods are destructive to fish food production as well as to the farm's earthwork. In selecting a site, these factors should be taken into account.

A favourable climate for tide fed fish farm management should have a dry season of one to three months to allow preparation of the soil for optimum algal production.

(*ii*) Availability and cost of farm inputs: The availability and cost of farm inputs, such as fish seed, fertilizers, feeds, pesticides, skilled labourers and farm managerial personnel should also be taken into account in site selection.

(*iii*) Infrastructural facilities: Proper consideration should also be given to infrastructural facilities particularly transportation, marketing and distribution systems.

3 General layout

A fish farm is a complex of establishments consisting of: (*i*) ponds of various kinds for different purposes, such as nursing ponds, rearing ponds for different production stages, and fish holding ponds; (*ii*) water control structures including embankments, canals, and sluices; and (*iii*) supporting facilities, such as roads, bridges, culverts, workshops and farmhouses. These supporting facilities are, however, excluded from the discussions in this paper. An effective farm layout is the arrangement of these facilities and structures in a proposed site based on the physical features of the area as well as the requirements of farm management. A general layout of a newly reclaimed 1 600 ha site is given in Fig. 1; the layout of individual management farm units within the reclaimed site is given in Fig. 2.

In the layout of ponds and other physical structures of a fish farm, maximum advantage should be taken of the topographical features of the site. This basic principle of farm design is not just to economize on the cost of earth work in construction; it is also to preserve soil fertility and furnish a better environment for operation of the farm.

3.1 *Major types of tide fed fish farm operations*

Tide fed fish farms generally have three types of operation which are given in Table V. It is apparent that Type I is a nursery system, Type II a system for table-fish production, and Type III a combination of Types I and II. Layout of a tide fed fish farm will be based on these operational types.

3.2 *Area requirement for nursery pond systems*

In the layout of a tide-fed fish farm for Types I and III operation, the first step is to know the area required for nursery ponds.

A nursery system consists of a fry-acclimatization pond,

TABLE IV

MINIMUM POND WATER LEVEL AND SALINITY RANGE REQUIRED FOR THE PRODUCTION OF THREE MAJOR TYPES OF FISH FOOD CROPS

Types of fish food crop	*Minimum level of water required*	*Range of salinity required* (‰)
Microbenthic algae	20–50	25–45
Filamentous green algae	30–60	5–25
Planktonic algae	70–120	0–25

TABLE V

MAJOR TYPES OF TIDE FED FISH FARM OPERATION

Types of operation	*Farm products*		
	Stocking material	*Intermediate products*	*Final products*
Type I	fry		fingerling
Type II	fingerling		table fish
Type III	fry	fingerling	table fish

fingerling rearing and fingerling-holding ponds. A fry-acclimatization pond is a small earth basin constructed in a corner of the fingerling-rearing pond. Milkfish fry are generally acclimatized in these basins under a regulated range of salinity for 24–48 hours before they are released to the fingerling rearing pond. The area requirement for the fry acclimatizing basin is about 0·01% of the area of the fingerling-rearing pond. The area required for a fingerling rearing pond can be determined by the number and size of fingerlings required, production capacity of rearing ponds, as well as the time and season of fry supply and of fingerling demand. The fingerling holding capacity of a pond depends principally on the environmental conditions, particularly the oxygen content of the pond water. Under normal conditions, one m^3 of water in the holding pond is capable of holding 1·7 kg of fingerlings. In general practice, milkfish fingerlings are stunted in the holding pond of the nursery and stored until they are needed either for stocking the rearing ponds of the farm for table-fish production or for sale to other farmers who are operating Type II farms.

Example:

A 50 ha milkfish farm produces 125 tons of table fish annually. Supposing that the average size of table fish is 0·25 kg (4 fish/kg) with a rate of survival (from the fingerling stage) of 95%, and the production capacity of the nursery pond is 450 kg/ha/crop with an average size of individual weight 2·5 g (400 fingerlings/kg), the area required for a fingerling-rearing pond can be calculated as:

$$(125000 \times 4) \times \frac{100}{95} \times \frac{1}{450} \times \frac{1}{400} = 2{\cdot}93 \text{ ha}$$

If the period between fry supply and fingerling demand is long enough to grow two crops, the area required for the fingerling pond for this 50-ha farm would be 1·46 ha. Further, assuming that three crops of table fish can be produced annually, the size of the holding pond can be calculated as:

$$(125000 \times 4) \times \frac{100}{95} \times \frac{1}{400} \times \frac{1}{1{\cdot}7} \times \frac{2}{3} = 515 \text{ m}^3$$

If the holding pond is trapezoidal in shape with a cross-section of 9·0 m^2 (with a bottom width of 3 m, depth 1·5 m, and a slope of side walls of 1:2), the length of the holding pond would be 57 m.

3.3 *Pond area requirements for different stages of production*

Layout of rearing ponds will be based on the systems that are planned to be adopted for fish population management. In principle, there are two major systems of fish population management: (*i*) one stage of production which is characterized by the stocking of a combination of different size groups of fish in a pond for the entire fish rearing season: and (*ii*) two or more stages of production which are characterized by the stocking of one size group of fish in a series of ponds of different sizes in a given rearing period. To maximize production, the area of ponds required in the series of production stages under the latter system of fish population management should be arranged proportionately to the minimum requirement of different size groups of fish during a specific rearing period. The number of stages in the series of production processes indicate the fish population management intensity under this system. The proportionate pond areas that are required for different stages of production in four levels of fish population management intensity are given in Table VI.

3.4 *Adjustment of water level and salinity range*

The water level and salinity range of a pond are basically determined by the tidal range, ground elevation, river discharge, rainfall and evaporation at the site. However, in ponds within the area of a farm site (or within a tract of fish farm land protected by the same perimeter dikes), water levels and salinity ranges can be adjusted to some extent if the topographical features of the area are used to their best advantage. For example, ponds which require deep water can be located in a natural depression, those that require a high salinity can be located in areas near the sluices.

3.5 *Optimum size, shape and alignment of ponds*

As a rule, the larger the pond size, the more efficient is the use of land and water and the lower the cost in farm construction; on the other hand, the smaller the pond size, the lower the earthwork maintenance costs and the more convenient the farm management. This is particularly true when the fish are harvested by gillnet. Generally speaking, for small- and medium-scale operations, say 10–50 ha units, a size of about 4–5 ha for individual rearing ponds is desirable; whereas for large scale operations (50–200 ha), a desirable size would be about 5–6 ha.

Ponds of rectangular shape are convenient for periodic harvest of fish by gillnet. These ponds should be aligned end to end on their short sides; their long sides should face the direction of the prevailing wind, in order to minimize the destruction of earth dikes by wave action.

3.6 *Ecological considerations*

The sites of coastal fish farms in tropical regions are usually covered by dense mangrove forest which, apart from its economic benefits, makes a valuable contribution to the

TABLE VI

PROPORTIONATE POND AREA REQUIREMENTS FOR DIFFERENT STAGES OF PRODUCTON UNDER FOUR LEVELS OF FISH POPULATION MANAGEMENT INTENSITY

Level of fish population management intensity	*Number of stages in production*	*Approximate period of time in each production stage (in days)*	*Types of rearing pond required*	*Ratio of pond area required*
1	One	140	Rearing pond (RP)	
2	Two	70	Rearing ponds for production stage I (RP_1) and stage II (RP_2)	RP_1:RP_2 1:4·5
3	Three	47	Rearing ponds for production stage I (RP_1), stage II (RP_2) and stage III (RP_3)	RP_1:RP_2:RP_3 1:3:9
4	Four	35	Rearing ponds for production stage I (RP_1), stage II (RP_2), stage III (RP_3) and stage IV (RP_4)	RP_1:RP_2:RP_3:RP_4 1:3.9.27

environment. In laying out a fish farm, measures to retain some portion of these forests should be given consideration

4 Typical design

The water control structures of a coastal fish farm consist of: (*i*) water-gates and canals for water supply and drainage; (*ii*) levees or perimeter dikes for protecting the farm land from tidal waves and floods as well as for retaining pond water; and (*iii*) dikes for partitioning individual ponds. In designing these structures, some guiding principles based on the author's practical experience, and basic data on physical features of the site are given below.

4.1 *Guiding principles*

4.1.1 *Quantifying the water requirement.* Since water control structures account for the major cost of fish farm development and water is one of the important fish farming inputs, quantification of water requirements for a fish farm in a given period of time is essential for planning and design of its water control structures. An example of this is given in Table VII.

4.1.2 *Providing adequate drainage facilities.* Drainage facilities for a fish farm not only control the water level as required for fish farm management, but should also take into consideration the requirement of improving pond soils

Periodic draining of the pond is a well established practice in fish farm management in oriental and east European countries. The main aims of this practice, as described by Wrobel (1967) and Tang and Chen (1967), are to supply the pond soils with atmospheric oxygen, increase the rapidity of mineralization of organic matter (which is accompanied by a decrease of acidity), control soil pests and, in some cases, provide a better physical environment for the growth of selective groups of fish food organisms.

Adequate drainage facilities are essential for the improvement of soil structure. This is especially true for newly reclaimed tidal swamplands. The coastal alluvia, consisting mainly of heavy clay, are generally highly acidic. This is due chiefly to the accumulation of iron sulphide in the subsoil to a depth of 0·5–1·5 m. This substance must be removed before the pond becomes productive for fish food organisms as well as for fish. The best way of removing it is by leaching and this is impossible without satisfactory drainage. Moreover, the roots of mangroves which constitute 30–50% in volume of the top soil of tidal swamplands would remain and not disintegrate if they are preserved in moist condition; these roots would become decomposed and gradually become productive soil humus if a proper drainage system is provided.

4.1.3 *Creating suitable environments.* The main aim of designing and constructing an adequate water control system for a fish farm is to create a suitable aquatic environment to meet the maximum requirements for the growth of fish-food organisms and simultaneously to meet the minimum requirements for rearing fish.

Except in the fish farming system that is exclusively based on artificial feed supply, the growth of fish-food organisms is essential for successful operation. However, in many cases, the environmental requirements for the growth of fish foods in brackish water conflict with those for fish. For example, the optimal range of salinity for the growth of microbenthic algae in ponds is 24–45 ppt, and their tolerance range is 10–55 ppt; whereas the corresponding ranges for milkfish are 5–25 ppt and 0–60 ppt respectively. In the design of water control structures for this type of fish farm, emphasis should be given to a maximum intake of high salinity water. This principle of fish farm design differs from the design of marine parks or aquaria, which is aimed at creating a suitable environment for fish only.

4.1.4 *Other guiding principles.* These include:

(*i*) Taking advantage of natural power systems in water supply and drainage: Gravitation and tidal action are the available natural energy that can be used for water supply and drainage. In the design of water control structures of a fish farm, these energy systems should be utilized to best advantage.

(*ii*) Preventing hazards: In designing physical structures for preventing hazards, particularly for storms and floods, economic consideration should be given equally to technical requirements.

(*iii*) Clearing the farm site: Land clearing is a very complicated work. This is especially true for the clearing of tropical rain forests, where skilled and experienced labourers, proper equipment and a well timed schedule are necessary. Different methods and procedures of clearing

TABLE VII
ESTIMATED WATER REQUIREMENT FOR A TYPICAL TIDELAND FISH FARM[1]

Months[2]	*Pond water level*		*Water loss*			*Water added*		*Net water requirement*	
	Average level (cm)	*Volume (m^3 ha)*	*Seepage (cm)*	*Evaporation (cm)*	*Volume (m^3 ha)*	*Rainfall (cm)*	*Volume (m^3 ha)*	*Pond water level increase or decrease (cm)*	*Volume (m^3 ha)*
April	25·0	2 500	6·0	16·0	2 200	6·0	600	25·0	4 100
May	30·0	3 000	10·0	24·8	3 480	15·0	1 500	5·0	2 480
June	45·0	4 500	10·5	16·0	2 650	38·0	3 800	15·0	350
July	50·0	5 000	11·6	7·0	1 860	42·0	4 200	5·0	(1 840)[3]
August	50·0	5 000	11·6	6·0	1 760	56·0	5 600	0	(3 840)[3]
September	45·0	4 500	10·5	8·0	1 850	21·0	2 100	(5·0)[4]	(750)[3]
October	40·0	4 000	10·5	18·0	2 850	15·0	1 500	(5·0)[4]	850
November	30·0	3 000	9·0	10·0	1 900	4·0	400	(10·0)[4]	500

[1] Data based on a fish farm in Tainan, Taiwan Province of China
[2] The fish rearing season starts from the second week of April and ends in the last week of November
[3] Excess water needs to be drained off
[4] Water level decrease

operations would be required for different types and densities of vegetation, structural development of ground soils and the pattern of rainfall and temperature.

4.2 *Physical features of the site*

Basic data on physical features of the farm site required for planning and design of water control facilities include: tidal range, river discharge and floods, ground level and topography, soil properties and evapo-transpiration, rainfall and rainfall distribution, and storms and cyclones. These data are usually obtainable from local government agencies concerned, such as the bureaux of weather, soils, forestry, and coast and geodetic survey.

The sites of tide fed fish farms are usually situated in the deltaic estuaries of major river systems. The principal distributaries run through the delta, usually forming a network of numerous channels. The tidal fluctuations in these areas are very complicated and usually vary with the gradient of the river bed, volume and velocity of river flow and distance from the shoreline. In general, the characteristics of tidal fluctuations in the river channels of deltaic areas, as compared to those of adjacent coastal waters, are as follows: (*i*) tidal range becomes small; (*ii*) period of ebb tide becomes long, while the period of flood tide becomes short; (*iii*) the mean tidal level becomes high; (*iv*) the above characteristics will become more conspicuous as the distance from the shoreline increases.

The deviations of tidal fluctuation on the farm site from that predicted in the tide table[1] can be measured to some degree of accuracy by setting up a tide staff to observe the tide at the river adjacent to the farm site. Based on the tide data obtained with the tide staff, a tide curve should be drawn parallelling the tide curve of the reference tide station. A ratio of tidal range, which is the ratio of tidal level at the site of the proposed farm to the corresponding level at the reference tide station, can be calculated (Table VIII).

Based on tidal data obtained from the tide staff at the site of the proposed fish farm, a design datum level can be established and thereby the ground elevations of the proposed farm site can then be determined. The height of various dikes as well as the depth of water supply and drainage canals will be designed on the basis of the established datum level

[1] In many countries a government agency issues an annual tide table to give predicted tidal level fluctuations by analysis of tide data obtained from tide stations in major ports. General information about tide fluctuation of a fish farm site can be obtained by referring to the nearest tidal station.

4.3 *Water supply and drainage systems*

Water supply and drainage systems consist of a number of water-gates and series of canals at different levels and of different sizes. These are to be designed for maximum utilization of tidal energy and gravitation to control adequately the inflow and outflow of water in a given period of time required by the farm management system. In most cases, water supply systems can be used simultaneously for water drainage. However, in farms with high intensity of management, they are required to be separated from each other to avoid possible contamination of the inflow water by the water discharged from ponds. However, in case of emergency, both systems can be used simultaneously.

4.3.1 *Design of main water-gate structures.* A coastal fish farm usually has three kinds of water gates: the main gate, secondary gate or division box, and tertiary gate. The main gate is installed at the perimeter dikes for the intake of an adequate quantity of tidal flow, and also for the discharge of water from the farm as required by pond water level control under a farm management practice. The secondary and tertiary gates are installed, respectively, at the dikes of the water canal and at the partition between ponds. The main water-gate is very important for a tide-fed fish farm because it controls a farm's water supply and drainage, the key factors for a successful fish farm operation.

Structure:

The structure of a main water-gate consists of tide stream wing walls, side walls, bed protection, sill and abutments. The intake structure for tide water flow (for water supply) is identical to that for pond water discharge (for drainage), except for the side walls which are designed in accordance with the slopes of the earth dike. The grooves for stop logs are usually set at the side of tide flow intake. Dimensions of the structure depend either on the capacity of tide flow intake or on that of pond water discharge depending on the farm management requirements. When the width of a gate is more than 1·5 m, two or more openings may be needed. Lifting mechanisms are usually employed in the gate control operation (Fig. 3).

Owing to the low bearing capacity of the foundation, the structure should be of lightweight construction. These structures should not exert a contact pressure of more than 150 g/cm^2.

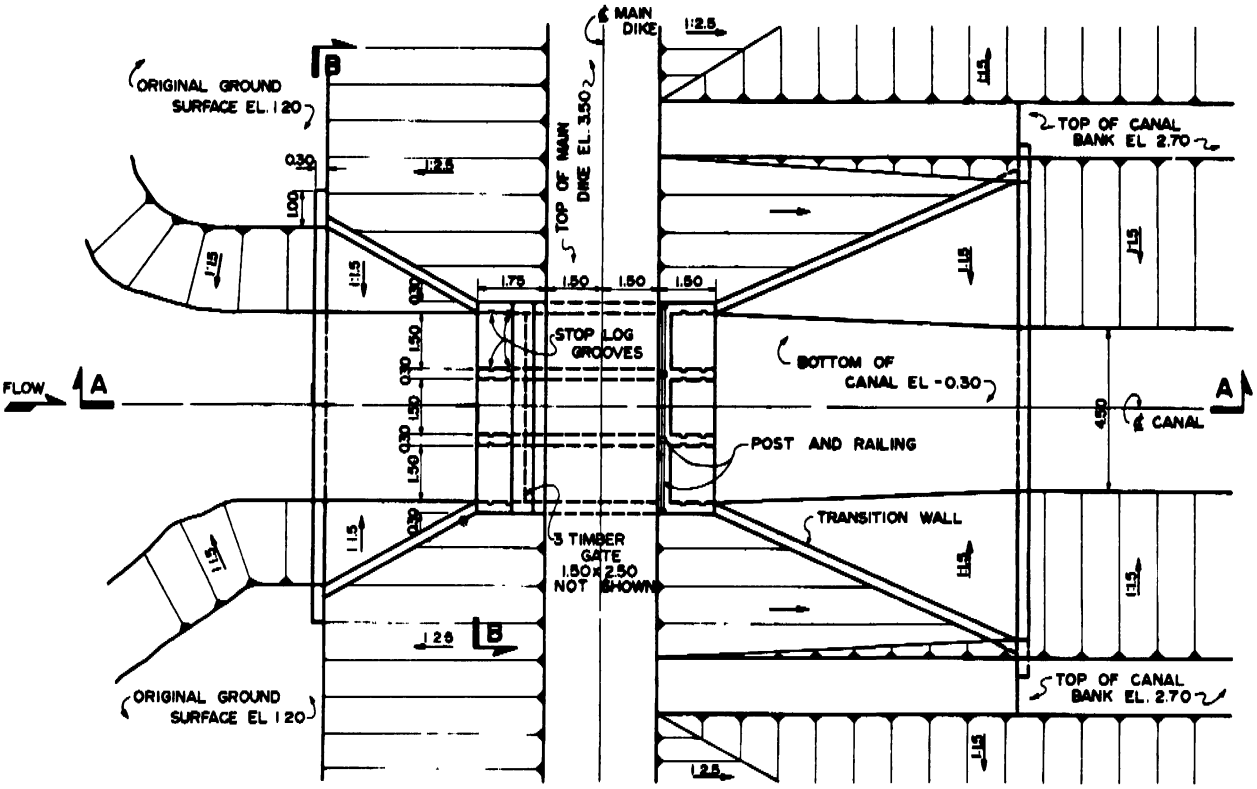
TABLE VIII

RATIOS OF TIDAL RANGE AT THE REFERENCE TIDE STATION TO THE RANGE AT THE SITE OF PROPOSED FISH FARM[1]

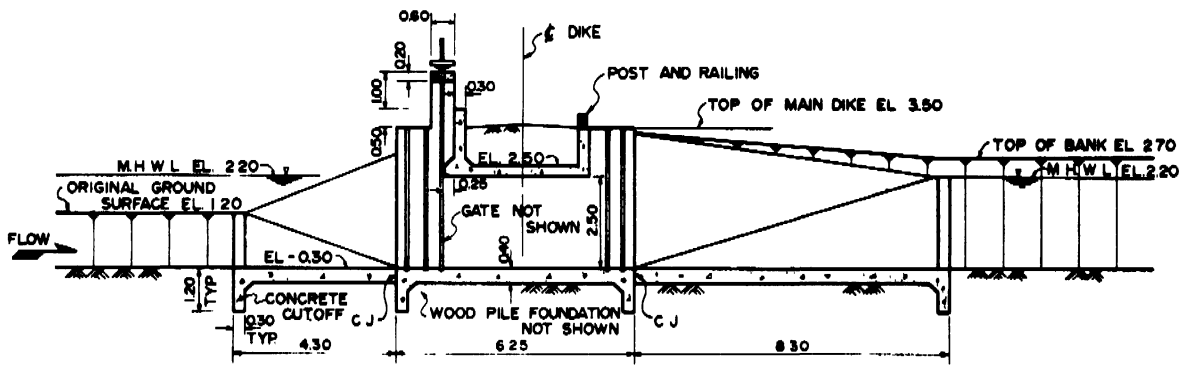
Tidal range[2]	*Height difference (m)*		*Time difference (hour:minute)*		*Ratios of tidal range*
	Reference tide station	*Site of the fish farm*	*Reference tide station*	*Site of the fish farm*	
LAT	-0·3	--			
MLLN	0·6	1·0		–	1·66
MHLW	1·1	1·5		-	1·36
MTL	1·6	2·0			1·25
MLHW	2·1	2·7		–	1·29
MHHW	2·8	3·5	--	–	1·25
HAT	3·2	---	--		
MHW			--	00:50	-
MLW				01:10	–

[1] Data were taken from Singapore Port (reference tide station) and the mouth of River Gelaney Patah (the site of a proposed fish farm)

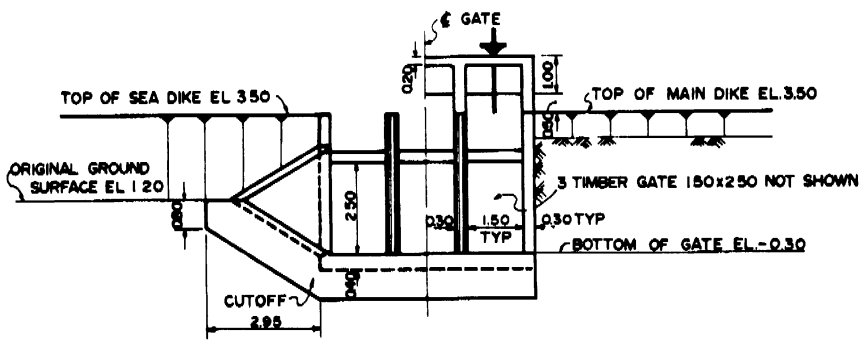
[2] LAT: lowest astronomical tide; HAT, highest astronomical tide, MLLW: mean lower low water; MHLW: mean higher low water; MTL, mean tidal level; MLHW: mean lower high water; MHHW, mean higher high water, MHW: mean high water; MLW: mean low water



PLAN



SECTION A-A



SECTION B-B

Fig 3. Typical design of a main water gate

Example:

It is assumed that a 40 ha farm with a designed water level of 0·3 m requires to be filled by three consecutive high waters of spring tide in a given period during the fish rearing season. It is further assumed that the farm is installed with two main water-gates and each is designed to have a gate opening 1·5 m wide. If water lost due to transferring is estimated to be 20%. water requirement for each gate during the high water of spring tide would be:

$$400\,000\ m^2 \times 0{\cdot}3\ m \times 1{\cdot}2 \div 3 : 2 = 24\,000\ m^3$$

Supposing that the established ground level of the farm site is 3·0 m and the tide curve on the day of water filling is as given in Fig. 4. the volume of tide water intake of this gate can be calculated by using the following equation:

$$Q = CA\sqrt{2g(H - h)} \cdot T$$

where Q – volume of water intake

C cross section of the flux (to be calculated by multiplying the width of the gate opening (1·5 m as designed) by the depth of the flux (diurnal tide fluctuations))

A – coefficient of discharge

g gravitational acceleration (9·8 m/s^2)

H tidal level in the river

h water level in the canal or pond

T – time (calculated at 0·2 hour or 720 second intervals)

It appears that the designed water-gates for this farm are adequate for its requirements of water supply (Table IX and Fig. 4).

In order to check the adequacy of the designed water gate for discharge of pond water in case of flood caused by heavy rainfall, it is necessary to examine the height and frequency of flood in the river system and the maximum rainfall within a given time in the region. For example, rainfall in the region amounting to more than 0·35 m/48 hours is assumed to occur at intervals of about seven years and levels of flood water in the river system at heights of above 4·6 m (on the basis of datum level or the tidal level of mean lower low water) at intervals of about ten years. The time required for draining off the excess rain water (which will damage the partition dikes by wave action and destroy the fish food crops by the reduction of pond water salinity) can be calculated by using the same equation as above. However, drainage by gravitation will occur only when the levels of flood in the river system are lower than that of the pond water, which will be at 3·65 m after 0·35 m rain water is added. It is, therefore, anticipated that the designed water gates for this 40 ha farm may have some difficulties in disposing of the rain water in the case of extreme heavy rainfall accompanied by a serious flood, but such a difficulty is expected to occur only once every 7 or 10 years.

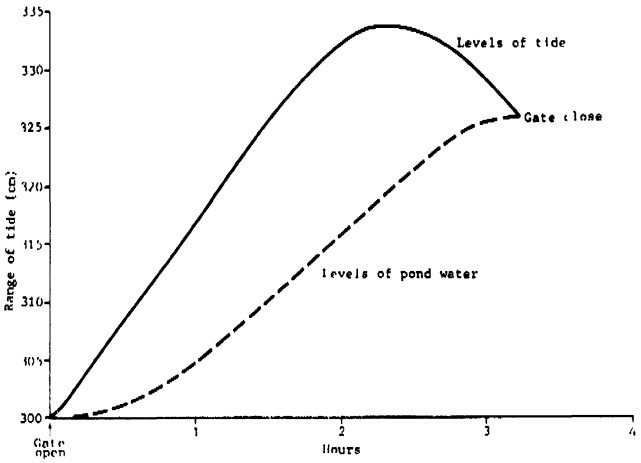


Fig 4. Graph shows the relations between the fluctuation of tidal level and pond water level under a water gate manipulation (refer to section 4.3.1)

4.3.2 *Design of water canals.* A coastal fish farm usually has two kinds of water canals: the main canal and subsidiary canal. The former is constructed either between two main water-gates or between one main water-gate and a division box and the latter between two division boxes. In the water supply the main canal distributes the take off

TABLE IX

EXAMPLE OF CALCULATION OF TIDE WATER INTAKE OF A PROPOSED WATER GATE

T		*Water levels in the pond*		*Water levels in the river*			
Seconds	*Hours*	*Elevation (m)*	*h (m)*	*Elevation (m)*	*H (m)*	*H h (m)*	*Q*[1] *(m^3)*
0	0	3·00	0·00	3·00	0	0	0
720	0·2	3·00	0·00	3·03	0	0	0
720	0·4	3·00	0·00	3·07	1·07	0·03	660
720	0·6	3·01	0·01	3·10	1·10	0·07	1 010
720	0·8	3·02	0·02	3·13	1·13	0·09	1 160
720	1·0	3·03	0·03	3·15	1·15	0·11	1 290
720	1·2	3·05	0·05	3·19	1·19	0·12	1 370
720	1·4	3·07	0·07	3·22	1·22	0·14	1 490
720	1·6	3·09	0·09	3·25	1·25	0·15	1 560
720	1·8	3·10	0·10	3·27	1·27	0·16	1 640
720	2·0	3·12	0·12	3·30	1·30	0·17	1 710
720	2·2	3·15	0·15	3·32	1·32	0·18	1 820
720	2·2	3·16	0·16	3·33	1·33	0·17	1 820
720	2·4	3·17	0·17	3·33	1·33	0·17	1 830
720	2·66	3·18	0·18	3·32	1·32	0·16	1 790
720	2·8	3·19	0·19	3·30	1·30	0·14	1 690
720	3·0	3·20	0·20	3·28	1·28	0·11	1 510
720	3·2	3·21	0·21	3·26	3·26	0·08	1 300
720	3·4	3·22	0·22	3·23	3·23	0·05	1 030
720	3·6	3·23	0·23	3·23	2·23	0·01	470

[1] Total for Q after 3·6 hours 25 150 m^3

from main water-gates to subsidiary canals and, in turn, to individual ponds; and *vice versa* in water drainage.

In addition to water supply and drainage required by pond water level control, canals have the function of regulating the water table within the farm, which is very important for soil improvement by leaching (refer to section 4.1.2). Canals also serve as shelters for holding fish temporarily. This treatment is required in fish stocking and in manipulating the fish population.

The alignment of the canal system should take maximum advantage of the natural waterways within the area of the proposed site.

Dimensions:

The cross section of the canal is generally of trapezoid shape with a side bank slope of 1:1 (for the soil type of alluvial clay). The depth of the main canals ranges from the level of mean higher high water (excluding the height of freeboard) to that of mean lower low water (the datum plan), and the subsidiary canal from the designed pond water level to the mean tidal level. The low limit of the water canals depend on the range of tide. Generally, a smaller tide range requires a lower canal bed.

When canals are used for sheltering fish temporarily, the size of the canal will be calculated by the quantity of fish to be held. Under normal conditions, the maximum quantity of milkfish that can be held by tidal water is about 1·3–1·7 kg/m^3.

Example:

The discharge capacity of a water canal is determined by the cross-sectional area of the canal and the velocity of the flow, and can be expressed by the following equation:

$$Q = AV$$

where Q = volume of water discharge
A = cross sectional area of the canal
V = velocity of flow

Since V can be calculated by the following formula:

$$V = R^{\frac{2}{3}} S^{\frac{1}{2}}/n$$

where V = velocity or flow
R = depth of water flow
S = canal bed gradient
n = coefficient of roughness (0·02)

And assuming that R = 1·25 m and $S = \frac{1}{5000}$,

then $V = 1{\cdot}25\ \text{m}^{\frac{2}{3}} \times \left(\frac{1}{5000}\right)^{\frac{1}{2}} \times \frac{1}{0{\cdot}02} = 0{\cdot}82$ m/sec

Further assuming that in case of heavy rainfall, the excess pond water has to be drained off from the above 40 ha fish farm within the time of a low water of ebb tide (3·5 hours or 12 600 seconds), the discharge capacity of the canal would have to be:

$$400\,000\ \text{m}^2 \times 0{\cdot}35\ \text{m} \div 2 \div 12\,600 = 5{\cdot}6\ \text{m}^3/\text{s}$$

Since $A = Q/V$

Therefore $A = 5{\cdot}6/0{\cdot}82 = 6{\cdot}8\ \text{m}^2$

The canal bed width b can be calculated from the equation:

$$(2b + 1{\cdot}25 \times 2) \times 1{\cdot}25 \times 0{\cdot}5 = 6{\cdot}8$$

Therefore b = 4·2 m

4.4 *Design of perimeter dikes*

The function of perimeter dikes is to retain water for use in the fish farming operation as well as to protect the farmland, fish crops and other farm facilities from destruction by floods and tidal inundation. Design and construction of these embankments must be based on sound engineering principles and economic feasibility. A typical design of perimeter dikes facing the sea or the river is given in Fig. 5.

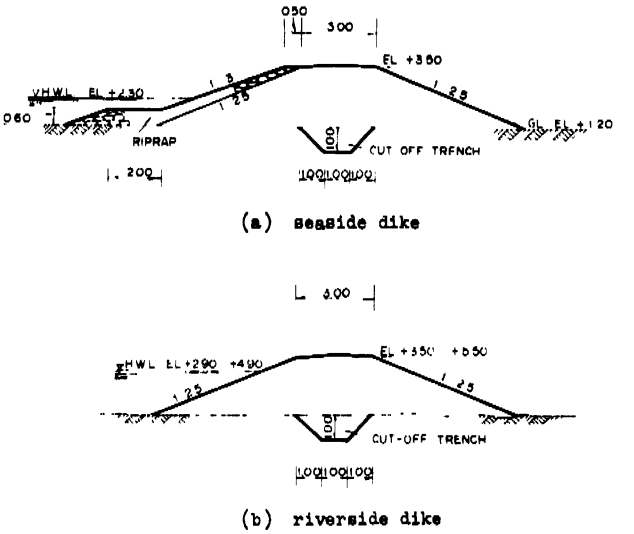


Fig 5 Typical design of the cross section of a perimeter dike. (a) seaside dike; (b) riverside dike

4.4.1 *Alignment.* The perimeter dikes of a coastal fish farm are aligned along the river banks or on the seaward side. In fixing the alignment, a belt of mangroves of 50–100 m wide should be left to protect the dikes against waves and currents, absorb energy and, to some extent, control wave floods and enhance the environment.

The alignment is usually determined by a contour survey of the site to be enclosed. Readjustments are required to avoid: (*i*) crossing streams or creeks which have a substantial volume of discharge; (*ii*) areas of extremely poor ground which will result in high construction cost; and (*iii*) siting near an actively eroding line of rivers or coasts.

4.4.2 *Cross section.* Cross section of the perimeter dikes should be designed to: (*i*) prevent over topping at high tide combined with a maximum discharge from the river system; and (*ii*) prevent failure due to slips and seepage.

Due to poor ground and soft foundation soil in coastal swamps, the embankment requires a process of consolidation before it becomes stable. Consolidation is a natural phenomenon which occurs under an inter-action between the settlement and bearing capacity of the foundation. Slip and collapse of an embankment constructed on poor ground occurs when irregularities or imbalanced conditions develop in the foundation.

Due to the high moisture content, low bulk density and high plasticity of alluvial clay, embankment material using this type of soil will result in high volume changes and surface cracks when drying up. Soil mechanics deal with the physical properties of soft embankment materials and poor ground construction. Based on test analyses made by Lim (1969) and Kato (1975), the height accompanied by the steepness of the slope of this type of embankment is limited to about 2·0 m.

The designed height of the perimeter dikes normally has a freeboard, after shrinkage and settlement, of 0·6- 1·0 m above the designed floodwater level, which is usually deter mined by the occurrence and frequency of flood levels at intervals of 10–15 years at the proposed farm site.

Example:
Consider a proposed farm site with a ground level of 3·0 m and the level of astronomical tide of 3·9 m, and supposing that the previous records indicate high flood-water levels over 4·6 m occurred at the site at intervals of 10 years, that the rate of shrinkage of the soil, after the embankment was settled, is 20% and that the freeboard is 0·6 m, the designed height of the perimeter dike can be calculated as follows:

$$(4.6\text{ m} - 3.0\text{ m} + 0.6\text{ m})\Big/\frac{(100-20)}{100} = 2{\cdot}75\text{ m}$$

4.4.3 *Leakage.* To maintain a watertight pond, leakage should be given due attention in dike design. Leakage is usually caused by the damage of the dike due to crustacean intrusion, particularly by *Thallassina, Anamala* and *Ucamanii.* They burrow in the soft mud under the dike and thereby cause the occurrence of 'piping' by which silt and sand particles are moved by seepage flow. Effective measures for preventing leakage include: (*i*) minimizing the amount of seepage flow (refer to next section); and (*ii*) minimizing the destruction by crustaceans by desalinizing and drying out the embankment soils.

4.4.4 *Seepage.* A normal seepage line in a dike constructed with homogeneous diking material on an impermeable foundation is a parabola (Fig. 6) and the seepage flow can be calculated by Casagrande's formula:

$q = k\sqrt{h^2 + d^2} - d$

where q – seepage flow (cm³/hour)
k – permeability coefficient (cm/hour)
h – height of water level
d – efficient width of dike

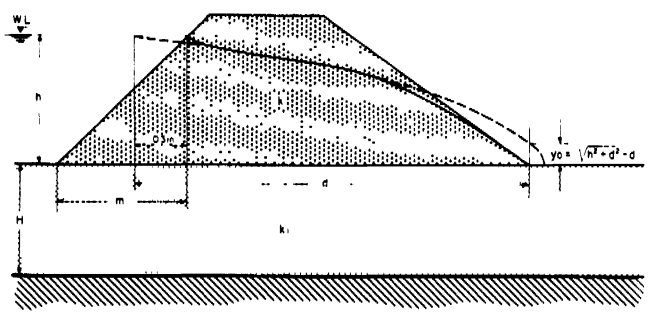


Fig 6. The seepage line in the dike with homogeneous material placed on a permeable foundation (after Kyoto, 1975)

When the dike is built on a permeable foundation, the seepage flow would be:

$$q = k\sqrt{h^2 + d^2} - d + k_1(h/d)H$$

where k_1 – permeability coefficient of foundation (cm/hour)
H = thickness of permeable foundation

Since the permeability of alluvial clay is relatively constant, the amount of seepage flow in a coastal fish farm depends mainly upon the levels of tidal fluctuation and effective width of the dike, which can be determined by calculation as shown in Fig. 6.

Example:
Assuming that permeability of the embankment and foundation soil is 1·32 cm/hour (Fireman's method) and the water level in the pond is kept constantly at 3·3 m, when the tidal level is at 4·8 m, the seepage inflow through the dikes respectively with three degrees of slope, *ie.* 1:1, 1:2 and 1:3, is given in Table X. When the tidal level is at ±0·0 (the datum level), the seepage outflow through the dikes corresponding to the same slopes as during the rising tides are also given in Table X. In order to minimize seepage, dikes would require a wider top and a larger slope footing, particularly when the dikes are situated at a higher range of tidal fluctuation.

4.5 *Construction*
Construction of a tide fed fish farm includes three major types of work: land clearing, earthwork and water-gate construction. Execution of construction requires detailed planning and budgeting, and a punctual schedule.

4.5.1 *Land clearing.* Because the ground is inundated by the tide and the sub-soil is very weak in structural development, clearing of this type of dense forest is expensive and time consuming. The clearing operation can be divided into three phases: (*i*) underbrushing; (*ii*) withering; and (*iii*) felling and burning.

(*i*) Underbrushing: Underbrushing, which has to be done manually, should commence when the foundations of the main water-gates and perimeter dikes are established. Creepers, undergrowth, young palms and jungle saplings up to about 10 cm in diameter are cut as close to the ground as possible. This operation must be done systematically in blocks and be completed immediately before the perimeter dikes and main water-gates are completed and the entire pond areas are ready to be filled with water. This cut vegetation should remain on the site to be used as organic matter to mix into the soil.

(*ii*) Withering: Withering is to kill the trees by filling the pond with water. It has been found that mangroves,

TABLE X
SEEPAGE FLOW THROUGH THE DIKES WITH THREE EFFECTIVE WIDTHS

Dimension of the dikes			*Maximum seepage inflow in rising tides*		*Maximum seepage outflow in ebb tides*	
Top width (m)	*Height (m)*	*Slope*	*Effective dike width (m)*	*Amount of seepage flow (cm³/h)*	*Effective dike width (m)*	*Amount of seepage flow (cm³/h)*
2·0	2·0	1:3	11·0	0·13	14	0·28
2·0	2·0	1:2	8 0	0·18	10	0·32
2 0	2·0	1:1	5·0	0·29	6	0·69

especially the *Rhizophora* and *Avicennia* groups, usually wither when their trunks are constantly soaked with water at a depth of more than 0·5 m for a period of 4–6 months. They will eventually die if continuously inundated for about a year.

(*iii*) Felling and burning: Felling should commence when the tree bark begins to peel, but before the foliage falls. The prerequisite of felling is to dry and harden the ground, which can be done by keeping the water table of the entire pond area at 0·3 -0·5 m below the surface for a period of 1–3 months depending on the climatic conditions. Either manual or mechanical methods, or a combination of both, can be employed for felling. The method chosen depends on factors such as availability of equipment wages of labour, type and density of vegetation, soils and climatic conditions. Generally speaking, small-scale operations, say, for a few hundred hectares, call for manual or a combination of manual and mechanical methods; large-scale operations call for mechanical methods.

The mechanical felling operation commences when the ground has been sufficiently dried and is hard enough to support heavy equipment. A variety of equipment has been developed for use in land clearing, *eg* cutting and shearing blades for directly cutting palms, saplings and small trees; the knockdown beam for felling large trees, and pluckers for uprooting small- and medium sized trees with lateral root systems.

The initial burning can usually be carried out when the dead trees have become dry. Pruning and reburning operations should start as soon as the site is cooled enough to allow access. This phase of operation is to remove all unburnt timber stumps left from the previous felling and burning.

(*iv*) Cost estimates: Cost estimates of underbrushing, felling and burning operations depend largely upon the information of tree counting which is done by field survey and provides information on the number, size, wood density and root systems of the trees and the growth of vines and other vegetation. The estimate will be re adjusted by the assessment of wages and other factors that affect work efficiency. Approximate labour requirement for underbrushing is about 20 man days/ha; for felling and burning operations of an average density of mangrove forest, 50 man-days/ha; and for pruning and reburning, about 70 man days/ha. The total labour requirements for clearing a typical tidal forest to the specifications for fish farm development, including underbrushing, felling, burning and pruning and reburning, are about 140 man-days/ha.

The cost of felling and piling by mechanical methods depends on the type of equipment used, efficiency of operation, tree counting, soil and climatic conditions *etc.* Generally, the requirement of machine working hours for a 250–270 hp crawler tractor would be about 0·05–0·07 ha/hour. (An example of calculating the hourly owning cost and hourly operating cost of a crawler tractor is given in Table XII.)

4.5.2 *Earthwork.* Earthwork for a coastal fish farm includes the construction of dikes and canals, and levelling of pond bottoms. These constitute the major cost of fish farm development and the bulk of the construction period.

(*i*) Manual method versus mechanical method: The adoption of the method(s) to be used will depend mainly on the nature of the work, cost of operation, and time requirement, as well as on social and political considerations. Generally speaking, the mechanical method has the advantage of shortening the construction period, lessening the cost of construction and improving the quality of the work; whereas the manual method will generate employment and save foreign exchange, both of which are particularly important to most developing countries. A comparison of these two methods on the basis of technical and economic assessments is given in Table XI.

(*ii*) Maintenance of foundation stability: Owing to poor ground and soft clayey soil, the bearing capacity of the foundation on which the embankment is to be constructed is low. In order to maintain the stability of the foundation, the following methods are generally employed:

(*a*) Preserving the mangrove root network: It has been found that the network of mangrove root systems can be used as piles to strengthen the stability of the foundation soil in embankment construction. In fact, after the tree is cut, mangrove roots continuously soaked with brackish water will not disintegrate. In preparing the ground for embankment construction, the network of mangrove roots should, therefore, be preserved.

(*b*) Replacing soft muds with sands and/or silts: since the perimeter dikes of tide fed fish farms are aligned along either the seaward side or the river bank, silt and sand are usually available for use in reclaiming the foundation. A dredger or sand pump can be used to move the sands and silt from the shores of the sea or river to a shallow dam which is made by bushes along the side lines of the foundation for holding and settlement of these replacement materials.

(*c*) Tilling with suitable load of embankment material to

TABLE XI
COMPARISON OF MECHANICAL AND MANUAL METHODS FOR EARTHWORK IN TIDE-FED FISH FARM CONSTRUCTION[1]

Item	*Mechanical method*	*Manual method*
Cost of construction by the nature of work (US$/m^3)		
perimeter dike	1·15	1·38
main canal	0·62	0·77
partition dike	0·62	0 46
levelling (US$/ha)	200 00	600·00
Labour requirement (man-days/million m^3)		
skilled labour	80 000	
unskilled labour		440 000
Construction period		
skilled labour (500 man days/million m^3)	160 days	
unskilled labour (1 000 man-days/million m^3)		440 days

[1] On the basis of a case study in the Philippines in 1974.

cover the slip surface: When the clayey soil in the farm site is used for diking material, the dumped soil should be allowed to spread to some extent over the berm on the landward side. This is done in order to maintain an equi librium between the foundation and the slip surface. Generally, the dumped soil is allowed to settle and dry for a period of 1–3 months. After this, an initial stability of the foundation will be established and the top of the dump will be able to support some light equipment to trim the soil and to form an initial profile of the dike as designed.

(*iii*) Construction equipment: For large scale development, suction dredgers with a capacity of 500–600 m^3/ hour are well suited for reclaiming embankment foundation and for embankment construction. Sand pumps with a capacity of 60–70 m^3/hour are also found to be very useful for this type of work.

When clayey soil in the site is used as embankment material, dragline excavators give good performance. They have to be supported on wooden mattresses when working in soft ground or on a light barge when working on small creeks or canals. A small dragline excavator with a bucket capacity of 0·3–0·5 m^3 seems to be convenient for opera tion and handling.

A crawler tractor with a lower ground contact pressure (0·2–0·3 kg/cm^2) gives outstanding performance in trimming the dumped soil for profile formation of an embankment and is also good for use in pond bottom levelling.

(*iv*) Cost estimate: The cost of earthwork is usually estimated by calculating the expenses of moving one unit volume of earth for diking, excavation and levelling. The cost for each unit will then be analysed on the basis of actual expenses for machinery, labour, tools and management. The cost of machinery will be further analysed on hourly owning cost and hourly operating cost. An example of cost estimates for earthmoving in constructing a 500-ha coastal fish farm is given in Table XII.

4.5.3 *Water-gate construction.*

(*i*) Construction pit: Water-gates are generally constructed *in situ*. To ensure successful construction, careful preparation of a construction pit is necessary. The bottom of the pit will gradually become hard enough to support the weight of a worker when de-watering of the pit can be efficiently carried out.

(*ii*) Pile ground: Due to soft foundation soil, piling of the ground on which the gate is to be constructed may become necessary. Specification of the pile depends largely upon skin friction for its bearing capacity. If mangrove or bamboo stakes are used, 30–40 stakes (about 5–6 m long) per 10 m^2 of ground surface area are sufficient to support the weight of a normal gate structure.

(*iii*) Cost estimate: The major components of the estimate consist of: (*i*) construction pit and its de-watering and backpiling; (*ii*) concrete work and its reinforcement and pile foundation; and (*iii*) gate manipulation instruments. An example of a cost estimate with unit cost of construction materials and labour requirement analyses for a typical main water-gate is given in Table XIII.

TABLE XII
COST ESTIMATES FOR EARTHWORK IN CONSTRUCTING A 500 HA COASTAL FISH FARM (IN US$)

Item	*Description*	*Quantity*	*Unit price*	*Total*
Embankment				
perimeter dike	cut, fill and compaction	200 000 m^3	1·15	230 000
partition dike	fill	120 000 m^3	0·46	55 200
Excavation				
main canal	cut and fill	10 000 m^3	0·62	6 200
secondary canal	cut and fill	8 000 m^3	0·62	4 960
Levelling	cut and fill	500 ha	200	10 000
Average/ha				612

(Estimates for unit cost of earthworks on page 117 second column)

HOURLY COST OF CRAWLER TRACTOR (75–100 HP)

Inital cost	30000	*Operating cost*	
Depreciation period	7 years	Repair cost	$\frac{30000 \times 78\%}{14000} = 1{\cdot}70$
Working yearly hours	2000		
Interest rate	10 percent per year	Fuel consumption, L/H	$8 \times 0{\cdot}40 = 3{\cdot}20$
Average capital.	$\frac{N+1}{2N}$ (N = year)	Engine oil consumption	$0{\cdot}07 \times 2{\cdot}00 = 0{\cdot}14$
Residual value	15 percent of initial cost	Transmission oil consumption	$0{\cdot}07 \times 2{\cdot}00 = 0{\cdot}14$
Owning cost		Hydraulic fluid consumption	$0{\cdot}04 \times 2{\cdot}00 = 0{\cdot}08$
Value to be depreciated.	30000 × (1–15 percent) = 25500	Filter (5% of fuel)	$= 0{\cdot}16$
Hourly depreciation	$\frac{25000}{14000} = 1{\cdot}82$	Operator	$= 0{\cdot}83$
Average capital:	$\frac{7+T}{7 \times 2} = 57$ percent	Operating cost	$= 6{\cdot}25$
Hourly interest cost	$\frac{30000 \times 57\% \times 10\%}{2000} = 0{\cdot}93$	Hourly cost	$= 9{\cdot}00$
Owning cost	2·75		

TABLE XIII
COST ESTIMATE FOR MAIN WATER-GATE CONSTRUCTION (A SET WITH THE SIZE OF 1.5 × 2.5 m) (IN US$)

Item	Quantity	Unit price	Total
Concrete	121·5 m³	27.70	3 365·50
Form	433·5 m²	2·45	1 067.00
Reinforcement	8·0 ton	523·10	4 184·50
Wood pile (0·20 m (diameter) × 7·00 m)	36·0 piece	30·00	1 107·50
Excavation	496.0 m³	0·46	229·00
Backfill	235·0 m³	0.23	54·00
De watering			461·00
Stoplog	4.7 m²	104·00	489·50
Steel angle and plate	50·0 kg	7.00	353·00
Handle wheel and spindle	1·0 set	230·00	230.00
			11 541.00

COST ANALYSIS FOR THE UNIT COSTS PER M³ OF CONCRETE (IN US$)

Item	Quantity	Unit price	Total
Cement	0·36 ton	49.20	18.00
Sand	0.54 m³	3.80	2.00
Gravel	0·94 m³	3·80	3·50
Mixing	1·00 m³	2·10	2.10
Placing	1.00 m³	1.50	1·50
Miscellaneous			0·60
Total			27·70

ESTIMATES FOR UNIT COST OF EARTHWORK (IN US$)

Item	Quantity	Unit price	Total
Perimeter dike (1 000 m³)			
crawler tractor	25 hours	9·00	225
dragline excavator	105 hours	8·00	840
miscellaneous			85
Partition dike (1 000 m³)			
manual labour	300 man-days	1.50	450
depreciation of equipment			10
Excavation of canal (1 000 m³)			
crawler tractor	25 hours	9.00	225
backhoe	40 hours	8·00	320
miscellaneous			75
Levelling (ha)			
crawler tractor	18 hours	9·00	162
miscellaneous			38

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Hydrometeorology in Pond Fish Culture

M. A. Szumiec

Abstract

The heat balance of ponds and the diurnal and seasonal changes of its components, as well as the temperature variations in the lowest air layer over the ponds and in the water have been determined at Gołysz Station, Poland. The correlation between the air temperature and the water temperature in the ponds has been found, and relation between the growth of individual carp and the sum of water temperature higher than 14° C was also determined.

The increasing intensification of carp production limits the solar radiation penetrating into the water, which in turn limits the photosynthetic activity. This fact stimulated detailed studies on the time/vertical distribution of solar radiation in ponds where different methods of carp farming were used.

The water balance, the sums and intensity of local precipitation and evaporation from the ponds have been characterized. Calculations have also been made to allow immediate determination of the rate of evaporation from pond surfaces, and the inter relationship between the evaporation flux, the water vapour pressure and wind velocity over the ponds.

Hydrométéorologie dans l'élevage des poissons en étangs

Résumé

Les travaux effectues a la station de Gołysz, en Pologne, ont permis de déterminer l'equilibre thermique des etangs et les variations diurnes et saisonnières de leurs éléments ainsi que les changements de temperature qui se produisent tant dans les couches d'air les plus basses au dessus des étangs que dans leurs eaux mêmes. Ce qui a permis de déterminer également, d'une part les relations entre les températures de l'air et de l'eau des étangs et, d'autre part, la relation entre l'augmentation du poids d'une carpe et la somme des temperatures de l'eau superieures à 14°C.

L'intensification croissante de la production de carpes limite la radiation solaire pénétrant dans l'eau, ce qui en retour limite l'activite de photosynthèse. C'est à ce propos que des etudes détaillées ont été entreprises sur la distribution verticale temporelle des radiations solaires dans des etangs où l'élevage des carpes se faisait selon des méthodes differentes.

On a également défini le budget hydrique, les sommes et l'intensite des precipitations locales et de l'évaporation des eaux des étangs. De même des calculs ont ete effectués afin de determiner de façon immédiate le taux d'évaporation de la surface des étangs, et les rapports réciproques entre le flux d'évaporation, la pression de la vapeur d'eau et la vitesse du vent au dessus des étangs.

La hidrometeorología y la piscicultura en estanques

Extracto

En la estación de Gołysz, en Polonia, se ha estudiado el equilibrio termico de los estanques y las variaciones diurnas y estacionales de sus componentes, así como las variaciones de temperatura en los estratos inferiores del aire, sobre los estanques, y en el agua. Se ha establecido la correlación entre la temperatura del aire y la del agua de los estanques y la relacion entre el aumento de peso de las carpas, singularmente, y la suma de la temperatura del agua mayor de 14°C.

La creciente intensificación de la produccion de carpas limita la penetración de radiaciones solares en el agua, lo que a su vez limita la actividad de fotosintesis. Este hecho ha movido a realizar estudios detallados sobre la distribucion cronologica vertical de la radiación solar en los estanques, utilizando diversos métodos de cultivo de carpas.

Se han determinado el equilibrio hidrico, la suma e intensidad de las precipitaciones locales y de la evaporación de los estanques. Se han hecho tambien calculos para permitir determinar inmediatamente el indice de evaporación de la superficie de los estanques y la interrelacion entre la evaporacion, la presion del vapor de agua y la velocidad del viento sobre los estanques.

1 Introduction

Hydrometeorological factors have an important influence on fish in the pond environment. In the middle geographic latitudes, low temperature limits the breeding and growth of warm-water fish and is therefore important to pond production. Water deficits which occur in many countries make it necessary to observe pond water balance carefully. In such small reservoirs as fish ponds, the large weather changes observed in middle latitudes cause frequent and large fluctuations of both biotic and abiotic processes. Determination of the characteristics of the hydrometeorological factors important in pond production requires a long period of observations over the whole range of their variability.

This paper summarizes the results of hydrometeorological research on pond environment which has been carried out at Gołysz Station (latitude 49° 58', longitude 18° 48', height above sea level 265 m) since 1955. The paper is concerned only with the farming season which is limited by local thermal conditions to the May-September period.

2 Heat balance components

Calculation of all the components of heat balance in previous reports (Szumiec, 1968, 1969, 1970) on research at Gołysz Station showed that 90% of solar energy, the main source of heat for ponds, is lost with evaporation from the water surface. Because of the change in direction of heat flux during the day, the remaining components, *ie*, heat exchange between the water and the pond bottom, and between water and air, have importance only when periods of several hours are considered (Fig. 1).

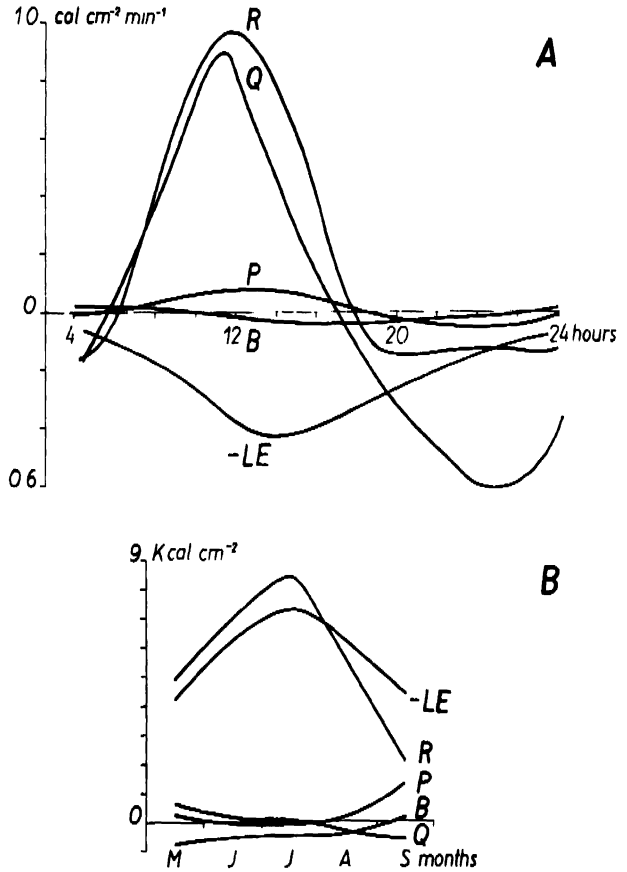


Fig 1. Changes in the mean diurnal (A) and monthly (B) values of the components of the heat balance of a pond

The research dealing with heat exchange (Szumiec, 1962, 1966) showed that in the lowest air layer over the ponds, the temperature follows an inverse diurnal pattern in comparison with the temperature variation over the soil or over large reservoirs. This means that during the day the temperature increases with height above the water surface and falls during the night (Fig. 2). This vertical temperature distribution appears only on sunny days and is caused by horizontal air advection coming from above surrounding land.

Detailed studies were also carried out on the thermal conditions in ponds (Szumiec, 1964, 1965, 1967, 1975b). On the basis of results obtained during fifteen years of study, the mean diurnal cycle in all categories of carp ponds and the seasonal cycle in larger ponds were determined (Fig. 3). This made it possible in individual years to calculate the deviations from the normal thermal values, allowing one to characterize the thermal conditions in each season. The probability of occurrence of the days with

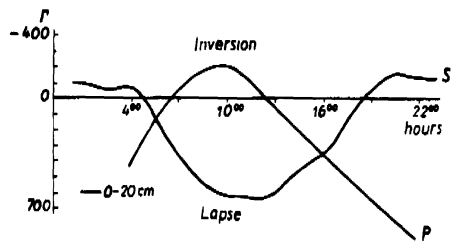


Fig 2. Diurnal changes of vertical temperature differences over pond (P) and soil (S) shown as multiples of the dry adiabatic lapse rate

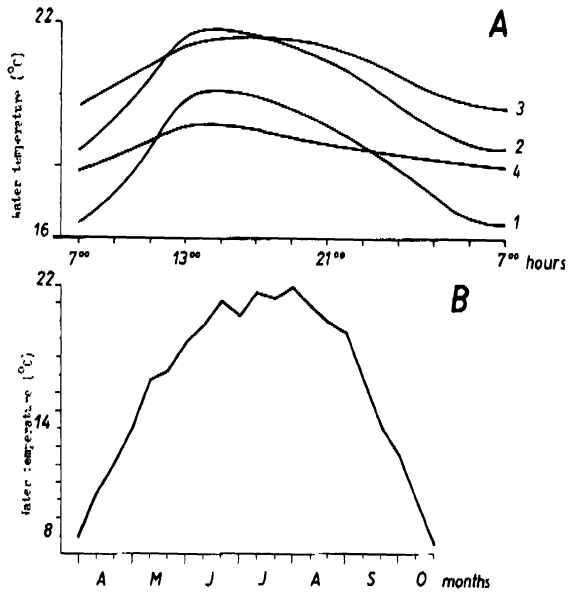


Fig 3 Mean water temperatures determined from many years of sampling

defined water temperature was also calculated as well as the dominant temperature for every ten days of the season. It has been ascertained that the depth z of the ponds influences the diurnal amplitude A and the vertical temperature gradient γ as follows:

$$A = mz^{-n}, \qquad \gamma = cz^{d}.$$

Under local climatic conditions at Gołysz Station the constants in the above equations assume values of: $m = 28$, $n = 0{\cdot}5$, $c = 400$, $d = 1{\cdot}1$.

3 Application of hydrometeorology data in pond management

To determine the water temperature (T_w) in ponds immediately on the basis of the air temperature (T_a), the regression between them was found:

$$T_w = a + b\,T_a$$

The computed parameters 'a' and 'b' made it possible to draw a monogram from which the mean decade water temperature in ponds can be read using the air temperature from the nearest meteorological station. It has also been proved that this method of temperature calculation can be applied to all ponds situated under similar climatic conditions. This method is accurate within about 1°C for water temperature (Szumiec, 1973).

It has been ascertained (Szumiec, 1975a) that the unit

weight of growth of carp fed intensively, is directly proportional to the sum of the water temperature higher than 14°C (Fig. 4). The fact that the weight of carp decreases when the temperature during the farming season is lower than 14°C, indicates that 14°C is the lowest temperature favouring carp growth.

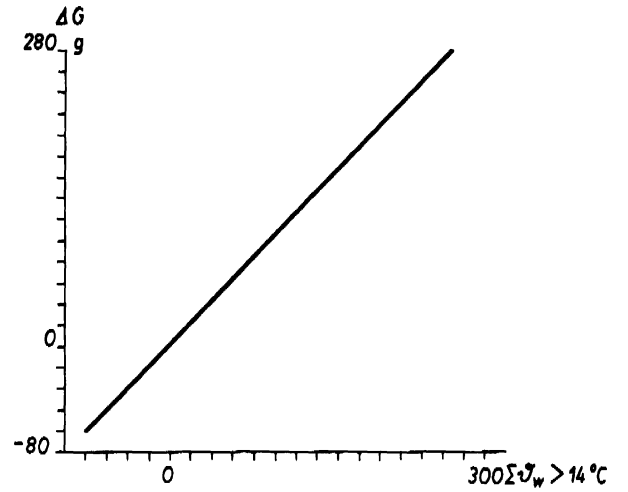


Fig 4. Relationship between the unit growth in weight of carp (ΔG) and the sum of temperature higher than 14°C ($\Sigma\vartheta_w$ >14° C)

Intensive carp production limits the penetration of solar radiation into ponds and thus limits photosynthesis. The appearance of an oxygen deficit in the water has facilitated accurate observations of this fact. On the basis of ten years of research, the mean time/vertical solar energy distribu tions (from 0·3 to 3 μ) in the ponds with three different production levels have been defined (Szumiec, 1975). A radiation intensity lower than needed for compensation of plant respiration was observed in the second part of the season in ponds (fed) with the highest production (Fig. 5). One possible explanation of this phenomenon is the earlier appearance of a short-period oxygen deficit caused by rapid changes of weather from sunny to cloudy conditions. A mathematical formula for time/vertical solar energy distribution was computed:

$$R(t,z) = A_{R,d}(z)\,|\sin\omega(z)t + T(z)|,$$

where $A(z)$ is the amplitude, $\omega(z)$ the frequency, and $T(z)$ the phase in daily cycle. Knowing the vertical distribution

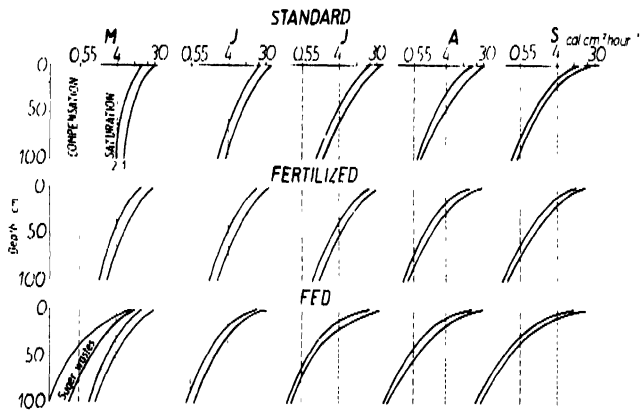


Fig 5 Mean estimate of vertical distribution of the radiation in standard, fertilized and fed ponds from May to September, presented in a semi-logarithmic scale against the background of two solar values characteristic for primary production: 1– in sunny weather, and 2 in average cloud cover conditions

of all these components of the above equation, it is possible to define the diurnal solar radiation distribution for any day or depth when only R_0 at the pond surface is known.

In the research on water balance, mean sums for long-lasting periods of local precipitation (Augustyn, 1975) and evaporation (Szumiec, 1973a) from the pond surfaces have been characterized (Fig. 6). This makes it possible to define the deviations of these factors in individual years from the normal values. The probability of occurrence of the defined sums and intensity of the precipitation was characterized. The method of intermediate definition of evaporation (E) from pond surfaces on the basis of the vertical rate of water vapour pressure ($e_0 - e_{200}$) and the wind velocity (v) over the ponds was formulated. The relation between the above mentioned values can be expressed by means of a linear equation:

$$E = e_0 - e_{200}(k + lv),$$

where constants k and l under our local conditions are 0·225 and 0·089 respectively.

The results obtained are not only published in scientific journals but also as papers describing the hydrometeorological characteristics of each season (Szumiec, 1974, 1975c). This provides an opportunity at the end of a season to analyse the factors influencing that season's fish production in the light of a background of atmospheric conditions.

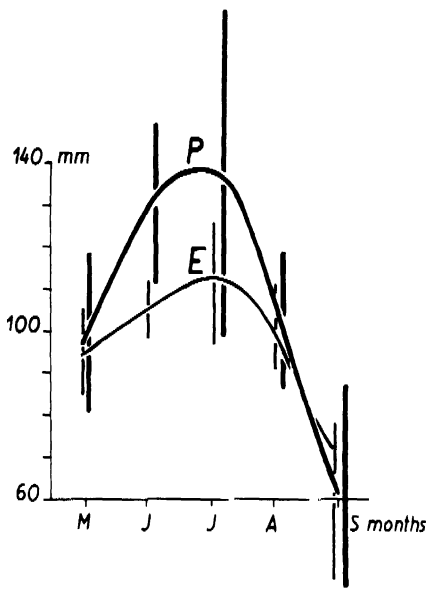


Fig 6. Monthly sums of precipitation (P) at Gołysz and the sums of evaporated water (E) from the pond surfaces. Bars indicate the standard deviations

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Lime Requirement and Application in Fish Ponds

C. E. Boyd

Abstract
A method for determining the lime requirement of agricultural soils was modified for use in the study of bottom mud in fish ponds. The relatively simple procedure, involving determination of the pH of mud in water and in buffered distilled water, gives a reliable estimate of the amount of lime needed to increase total hardness and alkalinity of pond water to 20 mg/l or more. The procedure was tested in 12 ponds with varying lime requirements, and total hardness exceeded 20 mg/l in all but one pond (19 mg/l).

Agricultural limestone is the preferred liming material, but other materials may be used provided the application rate is adjusted for the neutralizing value of the alternative liming material. Lime was most effective in increasing total hardness when spread over pond surfaces, but some benefit resulted from dumping 500 kg piles of lime around shallow water edges of ponds. The residual effect of liming depends on the rate of water outflow from ponds.

Besoins en chaux et chaulage des étangs piscicoles
Résumé
Une méthode de détermination des besoins en chaux des terrains agricoles a été modifiée pour pouvoir être appliquée à l'étude des sols des étangs de pisciculture. Cette méthode relativement simple, qui comporte le mesure du pH de la vase dans de l'eau naturelle et dans de l'eau distillée tamponnée, donne une estimation fiable de la quantité de chaux nécessaire pour accroître la dureté totale et l'alcalinité de l'eau des étangs jusqu'à une valeur de 20 mg/l ou plus. La méthode a été essayée dans 12 étangs présentant des besoins en chaux différents et la dureté totale dépassait 20 mg/l dans tous les étangs sauf un (19 mg/l).

La chaux agricole est le matériel de chaulage préféré mais d'autres substances peuvent être employées à condition d'ajuster le taux d'application en fonction de leur pouvoir neutralisant. La chaux est extrêmement efficace pour augmenter la dureté totale par épandage à la surface des étangs, mais on a obtenu des résultats intéressants en immergeant des masses (500 kg) de chaux en eau peu profonde le long de la berge des étangs. Les effets résiduels du chaulage dépendent du taux d'écoulement des étangs.

Necesidades y aplicación de cal en los estanques piscícolas
Extracto
Un método para determinar las necesidades de cal de los suelos agrícolas fue modificado para usarse en el estudio de el cieno del fondo de los estanques piscícolas. El procedimiento utilizado, relativamente simple, que comprende la determinación del pH del cieno en agua y en agua destilada amortiguada, permite obtener una estimación fidedigna de la cantidad de cal necesaria para aumentar la dureza y alcalinidad total del agua de los estanques hasta un nivel de 20 mg/l o mas. Se ensayo el procedimiento en 12 estanques que necesitaban cantidades diversas de cal, obteniendo una dureza total superior a 20 mg/l en todos los estanques menos uno (19 mg/l).

El material preferido para el encalado es piedra caliza para uso agrícola, pero pueden usarse también otros materiales, a condición de que se ajuste la tasa de aplicacion teniendo en cuenta la capacidad de neutralización de los materiales que se utilicen. El procedimiento más eficaz para aumentar la dureza total es esparcir la cal sobre la superficie del estanque, pero también se obtuvieron beneficios arrojando pilas de 500 kg de cal en las aguas poco profundas de los bordes del estanque. Los efectos residuales del encalado dependen de la tasa del efluvio de agua del estanque.

1 Introduction

Lime is frequently applied to fish ponds to improve water quality and the response to inorganic fertilization of soft waters and acid muds (Mortimer, 1954; Hickling, 1962; Arce and Boyd, 1975). Liming is recommended in the southeastern United States for ponds with waters softer than 20 mg/l total hardness (Thomaston and Zeller, 1961; Boyd 1974). However, until recently no procedure was available for estimating the amount of lime needed in a given pond. Boyd (1974) found a close relationship between the base saturation of bottom muds and total hardness of water in Alabama ponds. Total hardness of waters exceeded 20 mg/l when bottom muds were 80% or more base saturated. A procedure for estimating lime requirement of agricultural soils (Adams and Evans, 1962) was therefore modified to permit estimation of the amount of lime required to raise the base saturation of pond muds to 80% and the total hardness of the overlying water to 20 mg/l or more.

Methods used to lime ponds at the Fisheries Research Unit, Auburn University Agricultural Experiment Station, Auburn, Alabama are described and discussed in this report. These procedures were developed for use in the southeastern United States, but they can be adapted for use in other regions.

2 Estimation of lime requirement of ponds

Fertilization of ponds seldom produces good plankton growth if either the total hardness or total alkalinity is less than 10 mg/l. Responses to fertilization are variable in ponds with 10 to 20 mg/l total hardness and total alkalinity, but waters above 20 mg/l consistently produce adequate phytoplankton growth after inorganic fertilization. Therefore, liming is indicated if either the total hardness or the total alkalinity of pond waters is below 20 mg/l. Some pond waters which contain more than 20 mg/l total hardness or alkalinity, but are dark coloured because of the presence of humic substances, may also need lime to clear the water and permit better light penetration for photosynthesis (Hasler, Brynildson and Helm, 1951).

In waters where the total hardness and total alkalinity are virtually at the same level, such as those in Alabama (Boyd and Walley, 1975), total hardness alone may be used as a basis for determining the need for lime.

2.1 *Determinations of total hardness and total alkalinity*

These determinations are made from samples of surface water. Total hardness is determined by titration with 0·01 N ethylenediaminetetra acetic acid (EDTA) using eriochrome black T as the indicator. Total alkalinity is estimated by titration to the methyl orange end point with 0·02 N sulphuric acid. Procedures for these determinations are outlined by Swingle (1968), Golterman (1969) and American Public Health Association (1971).

2.2 *Collection of mud samples*

If it is determined from the tests for total hardness and alkalinity that a pond needs lime, the liming rate is estimated by measuring the lime requirement of the bottom muds. There is considerable variation in the chemical and physical properties of mud from different areas of a pond (Boyd, 1975), and mud must be collected at several randomly selected sites to obtain a representative sample for the lime requirement determination.

Based on statistical tests (Snedecor, 1956) with 16 ponds of different sizes, it is recommended that 12 samples should be collected from ponds of 1 ha or less and 25 samples from ponds of 2- 10 ha.

Mud samples should be collected from a variety of locations in a pond with an Eckman dredge or, if a pond has been drained, with a small shovel or similar device. To facilitate and simplify the analysis procedure, a 100 ml aliquot of each mud sample should be placed in a plastic bucket to give one composite sample per pond.

2.3 *Analysis of mud samples*

Lime requirement determinations are normally made by a soil-testing laboratory. However, the procedure is not complicated and can be conducted at most fishery stations.

Mix the composite mud sample thoroughly in the bucket and spread it in a thin layer to air dry. After drying, gently pulverise the sample with a pestle and mortar, and sieve through a screen with 0·85 mm openings. Prepare a p-nitrophenol buffer of pH 8·0 ± 0·1 by diluting 20 g p-nitrophenol, 15 g boric acid, 74 g potassium chloride, and 10·5 g potassium hydroxide to one litre with distilled water.

To 20 g dry mud in a 100 ml beaker, add 20 ml of distilled water and stir intermittently for one hour. Measure the pH of the mud/distilled water mixture with a glass electrode. Add 20 ml of concentrated p-nitrophenol buffer and stir intermittently for 20 minutes. After setting a pH meter at 8·0 with 1:1 mixture of concentrated p-nitrophenol and distilled water, read the pH of the mud buffer/distilled-water mixture while stirring vigorously. Use the values of mud pH in water and mud pH in buffered solution to obtain the liming rate from Table I. If the pH of the mud in the buffered solution is below 7, repeat the analysis with 10 g of dry mud and double the liming rate from Table I.

2.4 *Evaluation of technique to estimate liming rate*

The effectiveness of the procedure in estimating the liming rate was evaluated for four groups of three ponds, each of which had markedly different lime requirements (Table II). In all but one instance, the total hardness of the water exceeded 20 mg/l six months after liming. Values for total hardness were greater in Groups 3 and 4 (high lime requirements) than in Groups 1 and 2 (low lime requirements).

A total of 52 ponds on the Fisheries Research Unit, Auburn, Alabama have also been limed at rates established by the lime requirement method; the results are:

Total hardness 6 months after liming (mg/l)	*Number of ponds*
17·5–19·9	5
20·0–29·9	21
30·0–39·9	17
40·0–49·9	9

TABLE I

LIME REQUIREMENT IN KG/HA OF CALCIUM CARBONATE (NEUTRALIZING VALUE OF 100) TO INCREASE TOTAL HARDNESS AND TOTAL ALKALINITY OF POND WATER ABOVE 20 MG/L

Mud pH in water	*Mud pH in buffered solution*									
	7·9	7·8	7·7	7·6	7·5	7·4	7·3	7·2	7·1	7·0
	(kg/ha of calcium carbonate required)									
5·7	121	242	363	484	605	726	847	968	1 089	1 210
5·6	168	336	504	672	840	1 008	1 176	1 344	1 512	1 680
5·5	269	538	806	1 075	1 344	1 613	1 881	2 150	2 419	2 688
5·4	386	773	1 159	1 546	1 932	2 318	2 705	3 091	3 478	3 864
5·3	454	907	1 361	1 814	2 268	2 722	3 175	3 629	4 082	4 536
5·2	521	1 042	1 562	2 083	2 064	3 125	3 646	4 166	4 687	5 208
5·1	588	1 176	1 764	2 353	2 940	3 528	4 116	4 704	5 292	5 880
5·0	672	1 344	2 016	2 688	3 360	4 032	4 704	5 376	6 048	6 720
4·9	874	1 747	2 621	3 494	4 368	5 242	6 115	6 989	7 974	8 736
4·8	896	1 792	2 688	3 584	4 480	5 376	6 272	7 186	8 064	8 960
4·7	941	1 882	2 822	3 763	4 704	5 645	6 586	7 526	8 467	9 408

TABLE II

TESTS TO EVALUATE THE EFFECTIVENESS OF THE LIME REQUIREMENT PROCEDURE IN CALCULATING THE LIMING RATE FOR FISH PONDS IN ALABAMA

Pond group	*Total hardness before liming (mg/l)*	*Estimated lime requirement (kg/ha)*	*Agricultural limestone applied (kg/ha)*	*Total hardness 6 months after liming (mg/l)*
I	14·6	1 210	1 120	20·4
	10·6	1 210	1 120	19·0
	11·8	600	1 120	27·8
II	11·4	2 720	2 800	21·4
	11·8	2 690	2 800	26·2
	-	2 420	2 240	32·8
III	11·6	4 540	4 480	41·0
	13·2	4 540	4 480	32·0
	11·2	5 060	5 600	32·4
IV	8·8	8 330	7 840	39·8
	11·8	8 330	7 840	41·4
		8 330	7 840	37·8

Total hardness increased to 20 mg/l or more in all but five ponds. These five ponds seeped excessively and the lime was apparently lost in the outflow. The pH of the mud in ponds limed following estimation of the lime requirement with this procedure normally ranged from 6 to 7.

3 Application of lime

Agricultural limestone is the liming material of choice. Other materials may be used provided the liming rate from Table I is adjusted for the neutralizing value of the alternative liming materials. Substantial amounts of calcium oxide or calcium hydroxide must not be added to ponds which contain fish.

Best results are obtained by spreading the lime over the entire pond surface. However, some benefit may be obtained by dumping 500 kg piles of lime around the shallow water edges of ponds (Fig. 1). Although less efficient, this method requires much less labour when liming large ponds.

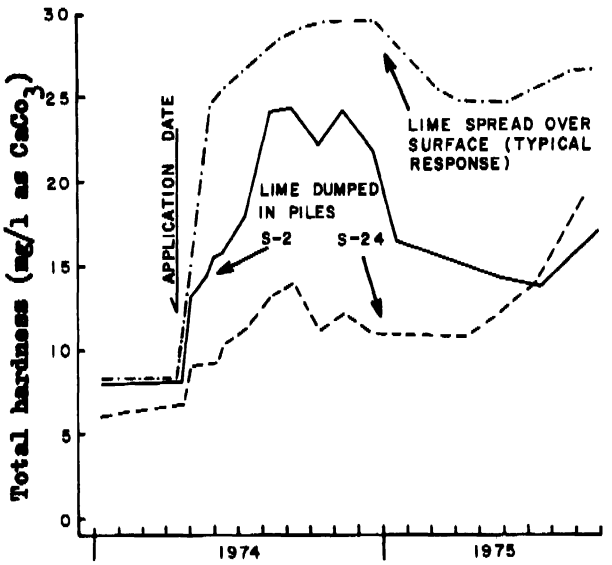


Fig 1 Comparison of effectiveness of liming by application in 500 kg piles near water's edge (S 2 and S 24 and spreading lime over pond surface (dotted line))

4 Residual effect of liming

4.1 *Effect of draining*

Five ponds which originally had waters with less than 12 mg/l total hardness were limed in the winter of 1973. The following autumn, the ponds were drained and then allowed to refill with surface run-off water. Three months after refilling, the total hardness of water in the ponds varied from 19·2 to 38·4 mg/l total hardness. In these cases, it is considered that residual lime in the mud increased the total hardness (and alkalinity) of the overlying water.

4.2 *Decline of total hardness in undrained ponds*

Hickling (1962) stated that an application of lime would last almost indefinitely in a pond with no outflow. However, most ponds lose some water to overflow and all ponds lose water through seepage.

In an experiment carried out for almost three years, liming was completely ineffective in Grier's Pond, a small pond with a water retention time of three weeks (Fig. 2). In four other ponds (S-11, S-12, S-13 and S 19) total hardness

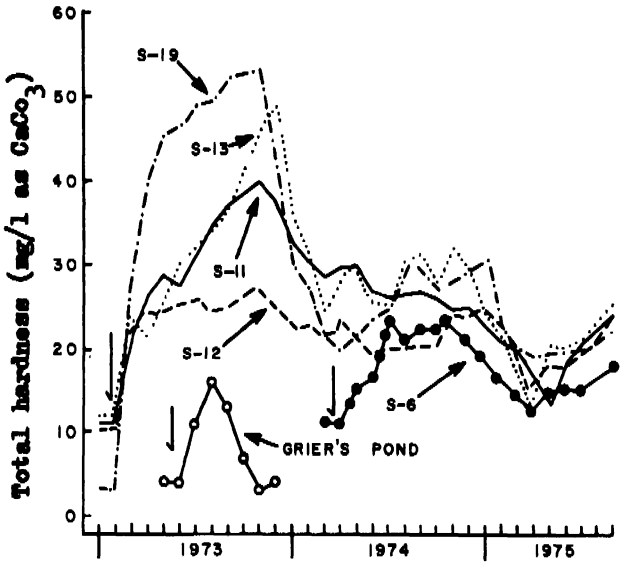


Fig 2. Residual effect of lime in ponds with different retention times and rates of overflow (vertical arrows indicate date of limestone application)

declined considerably within one year of liming, but was still about 20 mg/l nearly three years after liming (Fig. 2). These ponds lost water to overflow only during periods of heavy rainfall, and did not seep excessively. The decline in total hardness in the winter and spring of 1974 and 1975 represents periods of heavy rainfall with increased inflow and overflow. A sixth pond (S-6) had some overflow throughout the year. The increase in total hardness following liming and the residual effect of lime in S 6 was less than in S 11, S-12, S-13 and S-19 (Fig. 2).

These data suggest that routine tests should be conducted in limed ponds to ensure that total hardness and alkalinity remain at acceptable levels for optimal production.

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New Trends in Fish Farm Management

V. R. P. Sinha

Abstract

Recent advances in fresh and brackishwater conventional fish culture management techniques promise decidedly increased yields Throughout the world there is increased recognition of the value of polyculture, integration of agriculture and animal husbandry with fish farming, and recycling domestic wastes through fish culture Controlled breeding and production of seed of cultivable species, feed formulation according to a fish's nutritional requirements, maintenance of proper water quality, and control of diseases and pests are also being employed to achieve better production from cultivable waters

The development of intensive fish culture, where a very high rate of production is made possible by rapid water flow or increased aeration together with high stocking rates and use of rich protein food pellets, is likewise significant. The newer types of fish farms have all the characteristics of an industry where the possibilities of development and increase in production seem almost unlimited. Nevertheless, the adoption of these new techniques will be dictated more by the resources available and the needs of the individual country rather than by the availability of the technology.

Nouvelles tendances de l'exploitation piscicole

Résumé

Les recents progrès accomplis par l'exploitation piscicole traditionnelle en eau douce et en eau saumâtre permettent decidément d'escompter un accroissement des rendements. Dans le monde entier, l'on est de plus en plus conscient de la valeur de la polyculture, de l'intégration de l'agriculture et de la zootechnie à l'élevage piscicole, et du recyclage des effluents menagers dans la pisciculture. L'on utilise également l'alevinage contrôle et la production de géniteurs d'especes d'élevage, la formulation d'aliments répondant aux besoins nutritionnels des poissons, le maintien d'une qualite de l'eau adéquate, et la lutte contre les affections et les parasites pour obtenir une meilleure productivité des eaux qui se prêtent a l'élevage.

Il importe egalement de souligner le developpement de la pisciculture intensive, ou l'on peut obtenir un rendement considérable en assurant l'ecoulement rapide des eaux ou leur aeration accrue, en recourant à des taux d'empoissonnement élevés et en utilisant des granulés riches en proteines Les types les plus recents d'exploitation piscicole ont toutes les caractéristiques d'une industrie ou les possibilités de developpement et d'accroissement de la production paraissent quasi illimitees Néanmoins, l'adoption de ces nouvelles techniques dependra plus des ressources disponibles et des besoins des divers pays que des moyens technologiques.

Nuevas tendencias en el manejo de granjas piscícolas

Extracto

Los recientes progresos en las técnicas convencionales de piscicultura en aguas dulces y salobres prometen claramente un aumento de los rendimientos En todo el mundo se reconoce cada vez mas el valor del policultivo, de la integración de la agricultura y la ganaderia con la piscicultura, y del reciclaje de los desechos domesticos mediante la piscicultura También la reproducción controlada y la produccion de semillas de especies cultivables, la preparación de piensos según las necesidades nutricionales de los peces, el control de la calidad de las aguas y el control de las plagas y enfermedades permiten mejorar la produccion en las aguas cultivables.

Es igualmente significativo el desarrollo de la piscicultura intensiva, en la que una mayor rapidez de flujo del agua o un aumento de la aireación, unido a una mayor densidad de repoblación y al empleo de piensos granulados ricos en proteinas, permite conseguir un elevado indice de produccion. Los tipos más modernos de granjas piscicolas presentan todas las caracteristicas de una industria en las que las posibilidades de desarrollo y aumento de la produccion parecen casi ilimitadas De todas formas, la adopción de estas nuevas técnicas dependerá más de los recursos disponibles y de las necesidades de cada pais que de la disponibilidad de tecnologia.

1 Introduction

Empirical knowledge gained over several centuries from traditional rural pond culture has provided to some extent the basis for scientific fish culture. But today, great changes are taking place in fish culture—both in fresh and brackish water—which represent the combined forces of hard earned experience, scientific research and modern methods of management. Some of these changes will be discussed in this paper.

2 Advances in management of rural freshwater ponds and fish farms

Fish culture is carried out in a variety of enclosures and systems, although the old rural ponds still remain the most common and versatile structures. Most of these ponds do not fulfil many of the scientific criteria required for fish culture, *eg*, suitable topography, water supply and soil quality. Nevertheless, modified or retained in original form, they have frequent use as nursery, rearing and stocking ponds. In India, China and many other countries, particularly where a Chinese population has been established, cultivation of carps and other fishes, which grow rapidly, attain large size and are relished as food, has been practised in such ponds for centuries.

Recent advances in the management of freshwater ponds involve: application of organic and inorganic fertilizers (at times with trace elements), control of aquatic vegetation, eradication of pests and predators, pond stocking with quality 'seed' at appropriate rates and in appropriate ratios, and providing the fish with supplementary feeds. Advances have been made in the production of seed of carps through induced breeding and hatchery rearing. Coupled with these are improved methods of fry and fingerling transportation over long distances which have made their successful introduction and transplantation possible in a number of countries, so that more elaborate systems of polyculture are now possible.

2.1 *Polyculture*

Since various species of carps have different feeding habits, their mixed or polyculture allows a more efficient utilization of a pond's natural food resources than does monoculture. Polyculture has been most popular in China, India, Israel, and the USSR.

Lin (1955) has given the details of polyculture as practised with several species of carp in China. Other species combinations aimed at full utilization of the fish food available in a pond have been developed in other countries. Malaysia and Thailand have practised traditional Chinese carp culture but recently the use of grass carp (*Ctenopharyngodon idella*), together with tawes (*Puntius gonionotus*) and *Tilapia mossambica* also appears to be very successful. Rabanal (1968) indicated that a combination of tambakan or kissing gourami (*Helostoma temminckii*), tawes, nilem (*Osteochilus hasselti*) and gouramy (*Osphronemus goramy*) is an ideal combination in Indonesian ponds. In Taiwan Province of China and Hong Kong, bighead (*Aristichthys nobilis*), grass carp, common carp (*Cyprinus carpio*) and grey mullet (*Mugil cephalus*) are stocked with milkfish (*Chanos chanos*), *Tilapia mossambica* and sea perch (*Lateolabrax japonicus*). In Japan, the main combinations in farm ponds include common carp, crucian carp (*Carassius carassius*) and shrimp (*Leander paucidens*) with fish as the major component.

In France, species which are co stocked include: common carp, roach (*Rutilus rutilus*), tench (*Tinca tinca*) and pike (*Esox lucius*).

Polyculture in Yugoslavia utilizes common carp as the primary species supplemented by tench, catfish (*Silurus glanis*), pike perch (*Stizostedion lucioperca*) and pike. In Israel, a common carp tilapia mixed culture has been found very successful.

2.1.1 *Composite fish culture.* India has recently made a great leap forward in evolving and popularizing the

composite culture of the major Indian and Chinese carps (Lakshmanan *et al.* 1971; Alikunhi, Sukumaran and Parameswaren, 1971; Sinha, 1972). The Indian carps used were: catla (*Catla catla*), rohu (*Labeo rohita*) and mrigal (*Cirrhinus mrigala*). The exotic (*ie*, to India) carps were: grass carp (*Ctenopharyngodon idella*), silver carp (*Hypophthalmichthys molitrix*) and common carp (*Cyprinus carpio*). This compatible combination, which has been termed 'composite fish culture', is quite distinct from Indian polyculture of carps where only Indian major carps are reared together (Sinha and Gupta, 1975).

Centres in six Indian states utilizing composite culture have shown remarkable progress not only in augmentation of production but in extending the techniques of carp seed production. With the six-species combination, yields of 3 200–5 893 kg/ha/6 months have been obtained at different centres; and with respect to individual species, it can be noted that grass carp has shown a growth of 5 kg in a one year rearing period.

Since composite fish culture not only provides table-sized fish but also excellent brood fish, the composite fish culture units have been able to breed these carps for the first time in many states of India.

In further experiments on composite fish culture, fish production as high as 7 500 kg/ha/year and 9 396 kg/ha/year was obtained (Chaudhuri *et al.* 1974, 1975). In addition to the six species of carps, other fishes comprising a feather-back (*Notopterus chitala*) and three catfishes (*Ompok bimaculatus, Mystus seenghala* and *Pangasius pangasius*) were included to feed on minnows, insects, shrimps and molluscs. With extension of composite fish culture to ponds of about 2 ha, a production of about 4 000 kg/ha/year was obtained in West Bengal (Sinha and Sharma, 1976).

2.2 *Recycling of wastes and fish farming*

Use of domestic wastes for fertilization of ponds or feeding fish is an ancient practice but, because of the shortage and high cost of inorganic fertilizers and also availability of millions of litres of sewage near large cities and towns, the latter's use in fish culture has assumed growing importance and is yielding encouraging results. An average production of 3 4·5 tons/ha has been obtained with culture of carps where sewage is used in China, the Federal Republic of Germany, Hungary, Israel, Poland and the USSR. Almost thirty years ago, Vaas (1948) reported a production in Java of 3 000 kg/ha/year in oxidation ponds using effluent from septic tanks, diluted 1:3 with fresh water. Recently a production more than three times as high, 10 000 kg/ha/year of *Tilapia*, has been obtained in India by the Central Inland Fisheries Research Institute from ponds irrigated with domestic sewage (Gosh, personal communication). The utilization of sewage or sludge for fertilizing fish ponds is being developed in many areas. It should be possible to overcome public health hazards by modifications in the techniques of culture and monitoring and treatment of wastes.

The technique of using sewage to raise algae, which is directly introduced as food for cultivated organisms or used as a major component in the production of compounded feeds, is also of interest (Pillay, 1973).

2.3 *Use of low grade products in fish feeds*

There is also a growing tendency to convert low grade fish products into high quality fish or shellfish. The success of trout farming in Denmark, eel farming in Japan and Taiwan Province of China, and catfish farming in Thailand depends largely on the availability of cheap trash fish. Fish meal is now a major component in fish feed utilized for high production. With the high cost of conventional feeds, attempts are being made to develop formulations using inexpensive ingredients and recycled wastes.

2.4 *Agriculture, animal husbandry and fish farming*

Agriculture, animal husbandry and fish farming are now viewed as both complementary and supplementary to the ecological chain. Farmers have integrated fish culture with pig or cattle raising and also with rice cultivation, to contribute substantially to their economic and nutritional standards. An extensive type of paddy-cum-shrimp culture is a unique practice in certain parts of India. In Indonesia, fish culture in paddy fields is extensive and well developed, though it has suffered a setback through the use of pesticides for the rice crop. The area used for this purpose has declined from more than 1 003 000 ha in 1968 to about 80 000 ha in 1974. (The decline is also partly due to the use of fast yielding rice varieties which makes fish cultures relatively less profitable.) Nepal has introduced paddy-cum-fish culture into certain areas, where common carp is cultured. In general, paddy cum-fish culture has suffered because of the use of pesticides, but short-term fry rearing could very well be undertaken in paddy fields if proper techniques were devised. A three-way rotation of fish, soybeans and rice is being tried with considerable success by some farmers in Arkansas, USA (Pillay, 1973).

Domestic ducks and other water fowl are often used in the management of aquatic vegetation and the practice of duck cum-fish farming in eastern European countries has significantly contributed to food production and earnings. Application of these techniques has become popular in other parts of the world. In Nepal, carps have been cultured at 5 000–6 000 per ha with 400–500 ducks. Production of fish in these ponds showed an increase of 5–10% over that in ponds without ducks, and the ducks grew to an average weight of 2 kg in 45–50 days from the date of hatching (Rajbanshi, personal communication). In the Central African Empire, pig raising in conjunction with fish farming has increased farmers' earnings by more than three times, with a significant improvement in fish production (Pillay, 1973).

3 Advances in brackish water fish farm management

Brackish water fish farming is still in the experimental stage in the Americas and Africa but has a history of over 400 years in Indonesia, Taiwan Province of China and the Philippines, with the milkfish (*Chanos chanos*) as the principal species and grey mullet (*Mugil*) coming next. For many years these two non-carnivorous species were the only ones cultured there; the use of carnivorous species for farming developed rather recently. Efficient management of milkfish ponds involves their preparation, maintenance of proper water conditions, production of natural food organisms, supplementary feeding and pest and predator control. The modern method of increasing milkfish production by stock manipulation is based on a revision of the system of stocking one size group of fingerlings for each culture period with a single complete harvesting. The new trend is multiple stocking of different size groups of fingerlings

followed by repeated selective harvesting. The annual production using this system can be increased several times over that achieved by the traditional method (Ling, 1972). Fertilization of milkfish ponds with organic and chemical fertilizers is practised in Taiwan Province of China, and is being adopted in the Philippines and Indonesia. Supplementary feeds are given when the supply of natural food is poor.

Mullet culture plays an important role, notably in the Mediterranean area and southeast Asia, and is rapidly gaining popularity in temperate climates as well. A sophisticated use of mullet in fish culture is developing in Israel. Here, with common carp as a primary crop, *Mugil cephalus*, *M. capito* and *M. auratus* are used in polyculture.

Considerable advances have also been made in mixed brackish water fish farming in India (Jhingran, 1975). Experimental polyculture of two grey mullets, *Mugil parsia* and *M. tade*, and two penaeid prawns, *Penaeus monodon* and *P. indicus*, with repeated tidal flushing has given a net production of 2 666 kg/ha/year. In another combination of three species of mullet, *viz.*, *M. parsia*, *M. tade* and *M. cephalus*, the Indian major carps, catla, rohu, mrigal and kalbasu (*Labeo calbasu*) and the Chinese silver carp, grass carp and common carp in water of low salinity, a production of 1 700 kg/ha/8 months has been obtained (Anon., 1973). In monoculture of *Mugil tade*, a production of 1·5 tons per ha has been obtained when the fish has been fed artificially.

Farming of non-carnivorous species in both fresh and brackish water still depends mainly on the production within the pond of food organisms either naturally or by the use of fertilizers. Conversely, the culture of carnivorous species depends on feeds introduced into the ponds. Further development in farming both groups of fishes will depend to a great extent on the development and availability of efficient, economical artificial feeds.

Both fresh and brackishwater ponds are adversely affected by pests and predators. Modern agricultural insecticides and other agro chemicals show great promise in controlling them. Attempts are also being made through hybridization to evolve fish strains with resistance to unfavourable environmental conditions such as oxygen deficiency, adverse temperatures and unsuitable salinity, and also with better resistance to parasitic and infectious diseases. The food conversion capacity, nutritional qualities and taste of pond fish are also considered in this respect. In Israel and elsewhere genetic work on the improvement of common carp has been in progress for years.

In brackishwater fish culture, full utilization of the natural spawn available from the sea, better gear for fry capture, prospecting for new fry grounds, improved methods of pond preparation, use of fertilizers, supplementary feeds and pesticides, and stock manipulation will go a long way toward increasing production.

4 Running water fish culture

The beneficial effect of running water on the growth of fish is well known. Kawamoto (1957) and Chiba (1965, 1970) have shown that the yield and growth of carps in ponds with running water is 100 to 1 000 times higher than that in still water because of the elimination of growth-inhibiting metabolites and the continuous supply of oxygen. Carp culture in running water has become a commercial practice in Japan and the yield has reached hundreds of tons per hectare. Trout culture in running water has provided yields up to 4 000 tons/ha. Eels also grow better when they are cultured in running water.

Cage culture is very close to these systems. Both carp and catfish cage culture show great promise and are significant advances in fish culture. Cage culture is carried on extensively in Kampuchea, Thailand, and Viet Nam. A cage of 60 m^3 produces about 18 tons of fish per year in the Mekong River in southern Viet Nam (Tal, 1974).

Where water supply is limited, intensive culture can be carried on by recirculating the water in a closed system. In Japan, the water of an eel or goldfish pond is hardly changed at all. In a closed system, the water is purified by micro organisms which eliminate polluting substances while the water circulates between the culturing container and the filter bed (Hirayama, 1974). Aerobic bacteria attached to the surface of the phytoplankton assimilate and oxidize the polluting substances, and in turn the phytoplankton absorbs and utilizes the inorganic nitrogen and phosphate produced by the bacteria.

Nitrification by biological filters in closed system aquaculture is a primary method for removing ammonia from the culture water. The use and success of such filters for low density culture is well documented (Spotte, 1970). Microbiological filters are also feasible for high density fish culture (Meade, 1973). Though nitrifying filters are desirable, these are susceptible to malfunction with an immediate and rapid increase in ammonia. Johnson and Sieburth (1974) have suggested selective ion exchange using clinoptiolite as a back-up method for removal of ammonia in culture systems utilizing biofilters. This has an added advantage in that diseased fish can be treated with antibiotics without harming the nitrifying flora if an ion exchange column is used temporarily as an alternative method for the removal of ammonia.

Another problem to be faced in closed-system culture is that of oxygen deficiency. This is specially important when higher feeding rates are adopted to get better yields. This has necessitated introduction of a system of artificial aeration in closed systems. Increased volumes of air result in proportional increases in dissolved oxygen content, allowing greater weights of food to be offered to fish without depleting the oxygen content of the water. Further, this reduces the chemical oxygen demand of water. White catfish (*Ictalurus catus*) production was increased by over 100% by this method in comparison to non aerated culture (Loyacano, 1974).

5 Discussion

With improvements in conventional freshwater fish culture techniques, a production of 7–10 tons/ha/year has been achieved in different Asian countries. A rural pond which now has a subsistence level of production can have its production substantially increased with proper management and practically no investment in construction. In order to do this, effective extension activities are needed to improve the attitudes, skill and knowledge of fish farmers who have considerable experience but lack technical know how. A programme of operational research in fish culture is being undertaken in India so as to facilitate area development programmes.

The possibilities for integration of fish farming with agriculture and animal husbandry have special importance since many fish farmers are also part-time agriculturists, and many small farmers who keep a few ducks or other animals could also manage a small fish pond. It is estimated that there are about 10 million ha of deep-water rice fields in Asia and the Far East, most of which could be utilized for fish culture as a combined culture or rotation crop, if heavy use of pesticides were avoided.

In any case, fish farming can be an integral part of rural development. Fish culture in community development areas in India, the Integrated Rural Development Projects in Congo and in the Applied Nutrition Programmes in India, Indonesia, Republic of Korea, Lesotho and Sri Lanka, has increased food production and rural earnings and made substantial contributions to meet the nutritional requirements of rural populations (Pillay, 1973).

Lands unsuitable for agriculture can often be used advantageously for fish farming. At Malacca, West Malaysia, a fish farm was constructed on heavy lateritic, clayey, infertile, acidic soil (pH 5·0) with impeded drainage which supported practically no crop even after the addition of fertilizers. The pH of the soil and water was raised to neutral by the application of lime and the ponds made productive for fish culture. Many countries having large areas of unproductive, idle coastal land and water, are making efforts to utilize these for fish culture. Over 0·4 million ha of brackish water area has been developed for aquaculture in Australia, Kampuchea, China, Indonesia, the Republic of Korea, Malaysia, the Philippines, Singapore, Sri Lanka, Thailand and Viet Nam, and a further area of 1·5 million ha in these countries is available for similar development. In Taiwan Province of China, 1 600 ha of tidal land was reclaimed for milkfish culture, to demonstrate pond construction and management techniques to local farmers. The first year's production of 406 kg/ha has been raised to 1 338 kg/ha (Liang and Huary, 1972). More than 50% of the salt farms in Thailand have been converted entirely into brackish water fish and shrimp ponds. About 1 000 ha of rice fields have been converted into shrimp ponds in southern Viet Nam, and research in West Bengal (India) will go a long way toward developing 2 330 km^2 of marsh in this area.

A common characteristic of fish farms is the considerable cost of investment in pond construction. (In areas where it is feasible, culture of fish in net-cages can offset this expense to some extent, but there is still a need for investment.) Another characteristic common to most fish farms is the increasing use of supplementary feeds and fertilizers to obtain higher yields. Further increases in production will require higher inputs of this nature, as well as the use of considerable amounts of land and water and will pose problems to many countries.

Controlled breeding and the production of seed of cultivable species, formulation of feeds to meet their nutritional requirements and of high conversion rate, control of water quality, diseases and pests are being attempted everywhere to surpass the results of conventional methods. The development of high yielding technology for intensive fish culture either in well-aerated or recirculated water is also highly significant.

Intensive fish culture can thus be operative as a compact unit, where mechanization is possible to feed and harvest fish. This has all the characteristics of an industry where the possibilities of development and increase in production seem almost unlimited. This method has a great advantage in that the amounts of water and land required are relatively small, labour is more mechanized, and management easier. The unit may thus be comparatively easy to control. As long as the capital investment needed for this type of aquaculture is relatively less than that required for other protein producing industries, *eg*, poultry and beef, its development will gather momentum throughout the world. It must be cautioned, however, that its adoption will be dictated more by the resources available in a country and the country's particular needs rather than by availability of the technology.

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Problems of Warmwater Fish Seed Production

H. Chaudhuri and S. D. Tripathi

Abstract

Many of the important cultivable warmwater fish species spawn in rivers or estuaries or in the sea, making it difficult to obtain their seed for culture operations. Artificial methods of propagation have, however, been developed over the years for certain of these species. Techniques of successful spawning and rearing are still in their infancy with respect to species such as the grey mullets (*Mugil* spp) and milkfish (*Chanos chanos*).

The paper reviews the methods of seed production and distribution of both fresh- and brackishwater cultivable species, and discusses: (*i*) problems of egg, spawn, fry and fingerling collection from natural waters and those connected with the spawning of carps under artificial conditions; (*ii*) problems of seed production of catfishes and other air breathing fishes, tilapias, eels (*Anguilla* spp.), and (*iii*) seed production of the brackishwater and marine species, viz, grey mullets, milkfish, and yellowtail (*Seriola quinqueradiata*)

Problèmes relatifs à la production d'oeufs et d'alevins chez les poissons d'eaux chaudes

Résumé

Nombre d'espèces piscicoles importantes se reproduisent dans des fleuves, des estuaires ou des mers, ce qui fait obstacle à la collecte d'alevins destinés a des operations d'élevage. Toutefois, des méthodes artificielles de propagation ont été mises au point pour certaines espèces. Les techniques de reproduction et d'élevage sont encore peu élaborées pour les mulets (*Mugil* spp), chanos (*Chanos chanos*), *etc.*

La communication étudie les méthodes de production d'oeufs et d'alevins ainsi que leur distribution pour les espèces piscicoles d'eaux douce et d'eau saumâtre chaude. Elle examine: (*i*) les problèmes relatifs a la collecte d'oeufs, de larves et d'alevins en eaux naturelles ainsi que ceux de la reproduction des carpes en milieu artificiel; (*ii*) les problèmes de la production d'oeufs et d'alevins de silures et d'autres espèces a respiration aerienne, de tilapias, et d'anguilles (*Anguilla* spp); et (*iii*) la production d'alevins d'espèces marines ou vivant en eau saumâtre (mulets, chanos et sérioles (*Seriola quinqueradiata*) par exemple)

Problemas de la producción de peces para semilla en aguas cálidas

Extracto

Muchas de las especies cultivables importantes desovan en rios, estuarios o mares, lo que hace difícil obtener su semilla para la piscicultura. Durante los ultimos años se han preparado metodos artificiales de reproducción para determinadas especies. En el caso de especies como el mugil (*Mugil* spp.) y el sabalote (*Chanos chanos*), las técnicas de desove y cria están aun en la infancia.

En este documento se examinan los métodos de producción y distribución de semilla de especies cultivables de aguas dulces y salobres, teniendo en cuenta: (*i*) los problemas que plantea la recogida de huevos, larvas y jaramugos en aguas naturales y los problemas relacionados con el desove artificial de la carpa, (*ii*) los problemas que plantea la producción de semilla de bagre y otras especies que necesitan aire para respirar, tilapia, y anguila (*Anguila* spp.), y (*iii*) la produccion de semilla de especies de aguas salobres y marinas, es decir el mugil, sabalote y pez limón (*Seriola quinqueradiata*)

1 Introduction

Many of the important cultivable species of fishes spawn naturally or easily only in their natural habitats, thus making it necessary for a fish farmer to collect the stocking material directly from nature. Although the breeding requirements of some of these species are partially understood, much remains to be known before they can be bred in confined environments. Progress with respect to induction of spawning in captivity has been made primarily with the following groups: (*i*) the Indian and Chinese major carps (Chaudhuri and Alikunhi, 1957; Soin, 1959; Aliev, 1961); (*ii*) grey mullets (Tang, 1964; Yashouv, 1966, 1969; Abraham, Yashouv and Blanc, 1967; Shehadeh and Ellis, 1970; Alikunhi *et al*, 1971; Liao *et al*, 1971, 1972; Shehadeh, Kuo and Milisen, 1973; Kuo, Nash and Shehadeh, 1974); (*iii*) Asian catfishes (Ramaswami and Sunderaraj, 1957 and 1957a; Tongsanga, Sidthimunka and Menasaveta, 1963); (*iv*) the North American channel catfish (Clemens and Sneed, 1962); and (*v*) certain marine fishes (Shelbourne, 1964). Despite these efforts to obtain the necessary stock for culture, it is difficult to discard the traditional methods, especially so when aquaculture is fast becoming an important industry in several countries.

A number of hitherto uncultivated species are now in great demand and problems connected with their seed production and rearing are being investigated. The present review deals, however, only with the problems of seed production and distribution of warmwater fish species which are already being cultivated extensively.

2 Production of seed of freshwater fishes

2.1 *Collection of spawn, fry and fingerlings from natural waters*

2.1.1 *Collection of spawn from natural waters.* The fish fry trade has long been a well-organized industry in both China and India, providing employment for hundreds of people. Considerable expertise has developed over the years in the collection and handling of spawn and fry but in recent years the lucrative nature of the industry has attracted a considerable contingent of unskilled people which has affected the catches and their survival.

Spawn of Indian carps (*Catla catla, Labeo rohita* and *Cirrhina mrigala*) and of Chinese carps (*Hypophthalmichthys molitrix, Ctenopharyngodon idella, Aristichthys nobilis, Cirrhina molitorella* and *Mylopharyngodon piceus*) are collected during the monsoon months from flooded rivers by means of large conical bagnets. In Indonesia, the cyprinid *Puntius javanicus* spawns in rivers during the monsoon months and spawn and fry are collected with scoop nets made of fine cloth.

A number of studies have been carried out in India with a view to improving the collection of spawn from natural waters. Alikunhi, Chaudhuri and Ramachandran (1952) identified the causes of heavy mortality of spawn either during collection or in nursery ponds and suggested improvements: (*i*) proper fixing of the net to avoid resistance to fast flowing waters; (*ii*) a change in constructional design of the cod end of the net; (*iii*) periodic removal of spawn to avoid overcrowding in the receptacle; (*iv*) proper sieving of the collections to filter off predatory and competitor species; (*v*) avoidance of overcrowded conditions during temporary storage.

In order to meet increased requirements for carp seed, several riverine stretches in India have been prospected from 1949 onward and a large number of new spawn collection centres located (Jhingran, 1972). With a view to assessing the spawn-yielding potential of various centres on different rivers, new measures of spawn abundance and indices of spawn quality and quantity have been developed (Barrackpore, 1965). A standard spawn collection net has been devised which proved to be 200% more efficient than the gear in use in different parts of the country (Shetty, Malhotra and Ghosh, 1972). Catching efficiency has been increased by developing a new gear similar to a 4-seam trawl instead of the commonly employed 2 wing nets.

Chinese fry traders normally make a preliminary field estimate of the catch composition of spawn and fry of Chinese carps. The fry are sorted according to size groups and species using graded sieves and the oxygen requirements of the several species involved (Hora and Pillay, 1962). Their elaborate process of sorting, though of great ingenuity, is however costly and time-consuming, involving

high labour and transport costs and heavy losses during handling and distribution (Wu and Chung, 1964). Alikunhi, Chaudhuri and Ramachandan (1951) also tried to segregate the spawn of Indian major carps from a mixed collection of riverine spawn on the basis of their oxygen requirements but the method was not found very effective in the field. Mitra (1972) developed a field method for distinguishing Indian major carp spawn from spawn of minor carps based on size and the shape and size of the yolk-sac. This method helps in judging the quality of spawn as a whole but it does not help to segregate the desired spawn. Valuable nursery space is therefore wasted by stocking mixed collections which often comprise a high percentage of undesirable species. Riverine collections are also very undependable as monsoon vagaries and consequent heavy flood or drought often result in poor collections. These problems emphasize the necessity for locating new centres for the collection of quality spawn as well as the need for a more dependable method of production of quality fish seed.

2.1.2 *Collection of fry and fingerling from natural waters.* Castnets, dragnets and basket traps are commonly used as collection gear for fry and fingerlings.

The segregation of cultivable species from uneconomic varieties is fairly easy. The catch per unit of effort at several collection centres is very high and the operations are generally economically viable.

2.1.3 *Problems in fish breeding in confined waters through controlled natural or semi natural conditions.*

2.1.3.1 Breeding of common carp. Breeding of common carp (*Cyprinus carpio*) in confined waters is very common. Carp are bred in special ponds (Dubisch type) with a grassy raised bed in the centre as in Europe or in ponds with a hard or cemented bottom where 'egg collectors' like the 'kakabans' of Indonesia are provided. In China, *Eichhornia*, *Ceratophyllum* and *Myriophyllum* are used as egg collectors. In Japan, egg collectors made of polythene are being increasingly used. In India, breeding is usually undertaken in cloth 'hapas', fixed in ponds preferably without any fish population, and *Hydrilla* provided as the substratum for egg deposition (Alikunhi, 1960). This is an improvement over the 'kakabans' method as selected breeders alone are used and a high percentage of fertilization is ensured. In Hungary, hypophysation is employed for mass production of fingerlings. Fish are stripped after injection and fertilization is brought about artificially. The stickiness of the eggs is eliminated by use of urea and tannin and the eggs are incubated in jars. Hypophysation facilitates complete and advance spawning and ensures a high rate of fertilization and hatching irrespective of meteorological conditions (Woynarovich, 1969).

2.1.3.2 Breeding Indian and Chinese major carps. The traditional practice of breeding Indian major carps in special types of ponds, known locally as dry 'bundhs' has undergone several improvements in recent years (Dubey and Arjun Singh and Pande, 1972; Tripathi, 1974). As the factors responsible for the spawning of carps are not yet fully elucidated the practice of 'bundh' breeding is still not widely practised. Though the soil type is considered to be of prime importance, breeding has been observed in 'bundhs' constructed on clayey, silty and stony soils (Dubey and Tuli, 1961; Alikunhi *et al.* 1964). Kulkarni (1972) calls it eco-stimulus breeding as the required stimulus for breeding is provided by changes in the environmental conditions such as provision of more diluted and oxygenated water, change in pH, salts, *etc.*

It is one of the most important means of obtaining pure seed of cultivable carps, but the hatching techniques adopted are generally poor and result in great losses. Use of cement nurseries and glass hatching jars would be more economical and enable handling a larger number of eggs. The cloth 'hapas' which are used are not only expensive but are difficult to operate in the limited space in the 'bundh'.

2.1.3.3 Breeding the tawes *Puntius javanicus*. *Puntius javanicus* spawns in ponds with hard bottoms in Indonesia, Thailand and Malaysia. These ponds are specially prepared by leaving them dry for several days till the bottom soil cracks. Sometimes a part of the pond bottom is covered with sand and gravel. The pond is filled with well-oxygenated water and the spawners introduced; reproduction follows immediately. The eggs which are demersal hatch out in two or three days, the fry are collected when they are three weeks old (Hofstede, Ardiwinata and Botke, 1953).

Another method of breeding *P. javanicus* resembles the 'bundh'-breeding techniques of India. The construction of the spawning pond (0·1–0·2 ha) is undertaken in an area where sufficient rain water from the catchment gets collected easily. The pond is also provided with a pit (4 × 4 m), where the breeders are released. The fish are induced to spawn with the entry of fresh rain water after a heavy shower (Schuster, 1952).

2.1.4 *Problems of artificial propagation.* Although artificial propagation of salmonids has been known for over a century, artificial reproduction of cyprinids is recent and not always dependable. The difference between breeding salmonids and cyprinids is mainly due to difference in their genital structure, especially that of the female. Mature ova of female salmonids fall directly into the coelomic cavity, the ova of cyprinids stick to the ovarian tissue and in the case of common carp stick to the substrate or to one another soon after release by the female. Pressing the abdomen or flanks of a mature female or male is thus not enough to release sexual products in cyprinids and effect fertilization artificially. Instead it is necessary to use intraperitoneal or intramuscular injections of pituitary gland extract. Pituitary glands are removed from mature or maturing carp and preserved in acetone or alcohol. Since the Indian and Chinese major carps mature only once during a year, it is during this short period that the glands have to be collected. Inadequate knowledge of the maturity stage, especially that of a maturing fish, from its morphology makes the choice between mature and immature fish difficult and on a commercial scale glands are sometimes collected from immature fish. Common carp, which has comparatively large glands and remains mature for a greater part of the year, should be considered a good donor. In India, the problem of preparing and preserving the extract has been solved by developing techniques for ampouling and making it readily available to fish farmers (Ibrahim and Chaudhuri, 1966).

Administration of a single large dose of pituitary hormone, a common practice among Chinese fish breeders (Soin, 1959) results in ovulation, but affects the quality of eggs. Fractional injections of hormone approaching the

threshold dose, which give good results, are now widely used (Chaudhuri, 1960; Aliev, 1961; Wu and Chung, 1964) and effect saving of pituitary material. While natural spawning and fertilization is a common feature in injected Indian major carps, it is rarely so with Chinese major carps (Aliev, 1961, Wu and Chung, 1964; Chaudhuri *et al.*, 1967). Artificial fertilization by the 'dry' method is adopted (Vinogradov, 1968, Chaudhuri, Singh and Sukumaran, 1966).

The fractionation and purification of carp pituitary (Sinha, 1969, 1974) and Pacific salmon (*Oncorhynchus* spp.) pituitary (Donaldson *et al.* 1972) have been attempted successfully. However, since the effective doses of lyophilized second fraction of carp pituitary and that of SG-G 100 to precipitate spawning in Indian major carps and the catfish (*Heteropneustes fossilis*) are the same as that of the crude pituitary extract, purified preparations would not find much use in commercial breeding unless the inhibitory factor, if any, is eliminated (Chaudhuri, 1975).

An essential requirement for success in induced breeding is the selection of healthy breeders in prime condition. The stage of maturity of female breeders can be determined by collecting ovarian eggs by means of a catheter and microscopic examination. Visceral fat, common in *Catla catla* and *Ctenopharyngodon idella* from weedy ponds, affects the development of gonads, especially the ovaries, and such breeders do not respond to pituitary injections. *Catla* has been found to lose its adiposity and develop proper gonadial condition if transferred to shallow ponds by March-April and reared in crowded conditions. Three methods have been developed in Malaysia (Malacca, 1967) to bring about full maturity in grass carp. Tripathi (in press) has observed that grass carp, reared on a diet of predominantly terrestrial grasses, develop into good breeders and respond very well to hypophysation. Malformation of the male gonads is a very common feature in silver carp *Hypophthalmichthys molitrix* and unless a large number of breeders are available for selection, fertilization of the ova becomes a major problem. It is generally advisable to rear an adequate number of breeders and maintain them in ponds much before the onset of the spawning season.

Hypophysation is still rain dependent as the changes brought about in the physicochemical and climatic conditions of the environment are largely responsible for the success or failure of induced breeding. Failure of rains and prolonged drought result in poor development of the gonads. Rains being erratic, especially in a tropical country like India, prevailing air and water temperatures range too high and affect spawning. Spawning may sometimes occur at water temperatures above the optimum level but the percentage of fertilization and hatching is greatly affected and results in poor yields. The use of short periods of favourable weather conditions for successful breeding suggests that air-conditioned breeding and hatching centres may be a solution to this problem (Alikunhi *et al*, 1964a).

One of the problems encountered in seed production in India is the high mortality during incubation and hatching, due to sudden fluctuations in water temperature, presence of algal blooms producing oxygen bubbles which buoy up the eggs to the water surface, deposition of silt and poor oxygenation inside the 'hapa', and direct destruction of the eggs by common carp and tilapia (Panicker, Ibrahim and Bhowmick, 1969) and weed fishes (Tripathi and Sharaf, 1974) and in the case of common carp by gastropods (Banerjee, 1970). An indoor hatchery would eliminate these hazards and ensure economy and higher survival of hatchlings. The hatching of Chinese carp eggs requires flowing water. The physiological reason for this is not yet known (Kuronuma, 1968). Hatching in Zoug jars (Woynarovich, 1964) or the glass jar hatchery complex (Bhowmick, 1975) ensures quicker hatching and higher survival. An incubation net frame developed at the Saitama Fisheries Experiment Station for hatching Chinese carp eggs also has a high efficiency (Kuronuma, 1968).

Certain individual Indian major carps have been bred twice—instead of only once as is normal—within an interval of two months, during a single monsoon season, producing almost an equal number of eggs at each spawning (Barrackpore, 1972). This indicates the possibility of doubling the production of spawn from an individual fish. The use of artificial light for simulating longer photoperiods, higher temperatures and provision of nutritive food may help in bringing about early maturity and result in increasing the spawn production.

A major problem faced by aquaculturists in carrying out large-scale induced breeding operations is the lack of a suitable alternative to fish pituitary. There is a need to develop a natural or synthetic steroid or chemical hormone to meet the increasing world wide demand for commercial production of fish seed.

2.2 *Production of the seed of catfishes and other air-breathing fishes*

2.2.1 *Production of European catfish seed.* The European catfish or wels (*Silurus glanis*) is bred in ponds in Hungary, Yugoslavia and Czechoslovakia. They breed easily in storage basins (0·03–0·08 ha in area and 1·0–1·5 m in depth) if proper nests are provided. Spawning takes place when the water temperature rises to 20°C, hence filling of the ponds, placement of 'tent nests' and stocking of selected breeders should be done the same day. Hatching of the eggs could be done in hatching basins or Zoug jars. The young are averse to strong light which must be avoided (Huet, 1970).

2.2.2 *Seed production of channel catfish.* The North American Channel catfish (*Ictalurus punctatus*) breeds when the temperature is around 21–24°C. Commercial culture of the species was limited due to the non availability of the young. Production of channel catfish in hatcheries, though not difficult, was erratic and necessitated the development and refinement of hatchery techniques. It could be spawned in ponds, pens or aquaria with or without the use of hormones. Wire-meshed spawning enclosures (3 × 1·5 m) are fixed in spawning ponds and wooden kegs (1 × 0·25 m sides) or 50 l milk cans submerged in 60 cm of water to be used as spawning containers (Crawford, 1958). An equal number of males and females are placed in the pond at the rate of two pairs for each container. In the pen method, a male and a smaller female are placed in each spawning pen provided with a single spawning container. As the female might devour the eggs it is necessary to remove it from the enclosure after the eggs are laid. Males can be used two or three times for spawning.

The pen method has an edge over the pond method as it protects the spawning pair from intruding fish and provides opportunities for selection of each pair, delaying or hastening spawning, handling of the fish needing hormone injections, and immediate removal of spawners after egg laying

to enable stocking the pen with another pair (Clemens, 1968). The pond method can be adopted by an unskilled farmer, but the pen method requires skilled personnel capable of proper sexing and pairing the fish. The latter method also requires better quality brood stock.

Sneed and Clemens (1960) have described the techniques of hypophysation in channel catfish. A single pair is kept in a tank with running water and the female injected intra-peritoneally with 4–5 mg of acetone-dried whole ground pituitary per kg of body weight. The eggs are removed to a mechanical hatching trough provided with running water and a system of moving paddles for agitation (Nelson, 1960).

2.2.3 *Production of the seed of* Clarias *spp., other catfishes and air breathing fishes. Clarias* are indigenous to Pakistan, India, Bangladesh, Burma, Malaysia, Viet Nam, Thailand and the Philippines. *C. batrachus* is popular in India and *C. batrachus* and *C. macrocephalus* in Thailand.

In Thailand, the fry (25 mm) are collected from canals and ditches where they breed in comparatively calm waters of the marginal shallows about 50 cm below the water surface. The fry are collected by means of small fine-meshed handnets from spawning holes and transferred into a fry container. Generally, 2 000–15 000 fry are found in each hole. This method of collection yields approximately 50 million fry annually (Sidthimunka, Sanglert and Pawapootanon, 1968).

Pond breeding methods were developed by Wanichakorn (1957) and Sidthimunka and Ekuru (1959) to meet the increasing demand for *Clarias* fry by making holes in pond banks and providing some weeds therein for attachment of eggs. Tongsanga, Sidthimunka and Menasaveta (1963) and Sidthimunka, Sanglert and Pawapootanon (1968) induced breeding *C. macrocephalus* in small aquaria for commercial production of seed.

Although *Clarias* was bred in India as early as 1956 by using homoplastic pituitary glands (Ramaswami and Sunderaraj, 1957a), mass production was possible only through induced spawning by a massive dose of carp pituitary gland extract.

Several other species of catfish and air-breathing fishes (*Heteropneustes fossilis, Pangasius pangasius, P. sutchi, Channa* spp., *Anabas testudineus* and *Osphronemus goramy*) are cultured in the Indo-Pacific region. Their seed is generally collected from nature though they are all amenable to induced spawning.

The fry of *Pangasius sutchi, P. larnaudi* and *P. micronemus* are caught in Kampuchea in the Mekong river during the late monsoon months. They live on the bottom but regularly come to the surface to take in air. They are caught in slow moving water shaded by bushes and trees. Advanced fingerlings and juveniles are caught with dipnets (Hora and Pillay, 1962). Early spawning of *P. sutchi* is reported to have been accomplished by hormone injection. Recent attempts in India to breed the indigenous *P. pangasius* by pituitary treatment have met with some success. Induced spawning of indigenous cultivable air-breathing fishes on a mass scale has been developed and standardized in recent years (Dehadrai, 1975).

A low water column is the most essential requirement of the breeding environment of air-breathing fishes to enable easy aerial respiration. In *Anabas, Heteropneustes, Clarias* and *Channa* spp. aerial respiration starts five to eight days after hatching (Dehadrai, 1972; Banerji, 1974; Thakur, Pal and Khan, 1974). Rising to the surface for aerial respiration involves considerable loss of energy and in deeper waters may lead to exhaustion or mortality. Pandian (cited by Dehadrai and Tripathi, 1975) found the energy loss due to vertical trips of young *Channa punctatus* reared in 40 cm deep water to be 161 cal/day as compared to 92 cal/day for those which were reared in 2·5 cm deep water.

In India, fingerlings (30–100 mm) of *Clarias magur, Heteropneustes fossilis, Anabas testudineus, Channa marulius, C. striatus* and *C. punctatus* are collected from flooded fields, swamps and paddy fields by scoopnets, dragnets and traps and marketed alive for culture.

The gourami *Osphronemus goramy* breeds naturally in both streams and ponds. In India and the Philippines, no special preparation is made for spawning the fish except that aquatic weeds are planted in the ponds for construction of nests and egg deposition. In Indonesia, however, the fish is bred both in 'growing' and spawning ponds. The growing ponds are planted with *Hydrilla* for binding the bottom soil and providing shelter to the fish and branching stems of common bamboo are used for nesting. The depth of water is maintained at 70 cm. Four- to eight-year-old brood fish, maintained separately in special ponds about 50 cm deep and fed on *Carica* and *Colocasia* leaves and rice bran, are introduced in the growing pond at 1 female per 100 m^2 in the proportion of 3 females to 2 males. As soon as spawning begins, a fishy smell emanates from the nest and an oily substance comes to the surface. The eggs hatch out approximately 10 days after the breeders are introduced.

Spawning ponds for gourami measure 100 m^2 and are 60 cm deep at the inlet and 1 m at the outlet with muddy bed and steep banks. Branching stems of bamboo and fibres of *Arenga saccharifera* are provided for nest building. Ten female and five male breeders are stocked in such a pond and fed on *Colocasia* and *Carica* leaves at 5 kg per day and about 2 litres of rice bran twice a week. The females build nests in about 10 days and spawn in the next 3 days. Hatching takes another 3 days. The hatchlings are fed white ants at one tea cup per nest. When about 1 cm long, the fry are transferred to the rearing pond. If it is desired to re-use the pond, the nests can be taken out and the eggs hatched separately in earthenware jars. It is necessary to change the water regularly.

2.3 *Production of the seed of tilapias*

The tilapias (*Tilapia* spp.), though native to Africa, are now widely cultivated the world over. Seed production is not a problem in tilapias; it is their prolific breeding which requires control. Two methods, *viz*, association of tilapias with a predator, and monosex culture, have been tried to control over-population with varying degrees of success.

Since monosex culture of tilapias gave good results, the problem of obtaining all male or all female fry was sought to be solved by hybridization. Hickling (1960) obtained all male fry by crossing the males of an African strain (*T. hornorum zanzibarica*) with a Malayan strain of *T. mossambica*. Fast growth of the males is an obvious advantage as there is no fear of overstocking through wild breeding but they cause great damage to the dikes by building nests even in the absence of females. All-female hybrids would therefore be better despite their poor growth and lesser production. One 'Malayan' male (*T. mossambica*) when crossed with two 'Malayan' females (*T. mossambica*) gave

97 and 88% females (Malacca, 1963). Crossing male *T. hornorum zanzibarica* with females of *T. nilotica* in Uganda also resulted in the production of 100% male fry (Pruginin and Kanyike, 1965). All-male hybrids were also obtained, though irregularly, by crossing male *T. macrochir* with female *T. nilotica* in Ivory Coast by Lessent (1968).

All hybrids produced so far, however, belong to the microphagous group. Huet (1970) observes that production of herbivorous hybrids would be of great interest considering the ease with which they can be fed artificial food. It is also suggested that fry raising must be separated from production of fish as these are two distinct operations.

2.4 *Production of elvers*

The catadromous eels (*Auguilla* spp.) pass from one to three years of their life in the sea depending upon the area they come from. The European eel (*Anguilla anguilla*), the American eel (*A. rostrata*) and the Japanese eel (*A. japonica*) are economically very important.

Eel culture is practised intensively in Japan where a very high rate of production is obtained. Elvers (60–70 mm/0·16–0·2 g) are captured in winter at the mouths of water courses with nets and stocked in ponds for culture until autumn whence they attain a size of 150–200 mm and a weight of 5–8 g. Cannibalism is a highly characteristic feature and young eels need to be graded 5 to 6 times before they reach a size of 100–150 mm. These are stocked again but in different ponds according to their size. These are known as seed fish and used for stocking large ponds which produce eels for the table (Huet, 1970).

The Indian eels, *A. bicolor* and *A. bengalensis*, have also been reared recently and found to have high growth and high production potential. It has been found that their elvers attain marketable size (350 mm in length and a weight of 100 g) in running waters in one year (Dorairaj, 1976). An elver resource survey is needed to determine the areas and period of their abundance to help locate centres for their collection on a large scale.

3 Production of seed of brackish water and marine fishes

3.1 *Production of grey mullet seed*

The grey mullets (*Mugil* spp.) are raised in fresh and brackishwater ponds in China, Hawaii, Hongkong, India and Israel. In India, China and Hongkong, they are cultured along with major carps; in Hawaii with milkfish and in Israel with common carp and tilapias. The most important species of mullets are *Mugil cephalus*, *M. capito*, *M. tade* and *Liza macrolepsis*.

Mullets migrate to the sea for spawning though they do attain maturity in brackish water lakes and estuaries. Hendrickson (1969) reports natural spawning in captivity when pond-grown mature mullets were transferred to tanks where pure sea water was being circulated. It is believed that mullets need waters of high salinity for proper fertilization of their eggs.

In China, dipnets are used for catching mullet dry during low tides. Fixed dipnets, operated from the shore, are also used. In India, pieces of coarse cloth dragged by two persons constitute the gear in West Bengal; while fine-meshed dragnets and castnets are used in Tamil Nadu, and Chinese dipnets are commonly used in Kerala.

Mullet seed is quite tolerant of wide fluctuations in salinity and enters the estuaries and brackish water lakes as fry and fingerlings where they are taken in impoundments along with tidal water and reared in association with other species, including predators and competitors. However, it is possible to identify the different species of mullets and segregate them for selective stocking (Sarojini, 1958).

Production of grey mullet seed through hypophysation has been tried in Taiwan Province of China (Tang, 1964; Liao *et al*, 1971, 1972), India (Chaudhuri, 1968; Chaudhuri *et al*, in press), Israel (Yashouv, 1966 and 1969; Abraham *et al*, 1967), and Hawaii (Hendrickson, 1969; Shehadeh and Ellis, 1970). While ovulation, fertilization and hatching were carried out successfully, further rearing seemed very difficult. In Taiwan Province of China, the problem of selecting and securing mature, uninjured mullets from the sea was solved by developing a special raft fitted with an outboard motor for quick transport. Though the effective dosages were found to be 3·5 mullet pituitary glands combined with 30 RU of Synahorin, it was felt that more pituitary glands and less Synahorin in the first injection and less glands and more Synahorin in the second injection would be better. The time between the two injections was cut to 12 h but it has not been possible so far to shorten the ovulating time by less than 24 h. A high percentage of hatching (over 70) is possible when a high dissolved oxygen content is maintained and minimum variations are allowed in water temperature and salinity (Liao *et al*, 1972).

Larval rearing was found to have, at least, two critical periods, the third to fourth day and the 11th to 13th day. The survival rate was less than two per cent during the second critical period and the larvae continued to die till the 18th day, by which time the survival rate was less than one per cent. This problem could be partly solved by using freshened sea water from the sixth or seventh day onward but the timing and freshening rate require further studies. Both natural and artificial feed for mullet larvae are still a problem and require further studies. The newly-hatched larvae cannot tolerate light of high intensity, at least, up to the 13th day, hence studies are required to be conducted on the optimum light intensity tolerance to reduce unnecessary mortality.

In Hawaii, Kuo, Nash and Shehadeh (1974) developed standard practices to breed the grey mullet under controlled conditions. The dosages of hormone to be administered have been established in relation to the stage of maturity of the female, which could be determined by the size of the intraovarian oocytes. Gravid females, having a mean egg diameter preferably larger than 650 µ but not less than 600 µ, require a total dose of 12 µg of partially purified salmon gonadotropin per g body weight. Females with small and less developed eggs receive a higher total dose (21 µg per g body weight). The injection is always fractional: one-third of the total dose is followed 48 h later by the remaining two thirds.

Out-of-season vitellogenesis of intraovarian oocytes of captive grey mullet has also been induced by the manipulation of photoperiod and temperature regimes (Kuo, Nash and Shehadeh, 1974). Spawning can be induced in such females where the oocytes have progressed to the tertiary yolk globule stage but the egg size has remained below the effective range for injection (600–650 µ) by daily injections of pituitary gonadotropins increasing the doses from an initial 0·12 to 3·4 µg per g body weight.

The manipulation of photoperiod and temperature, alone or in conjunction with the use of exogenous hormones, helps to achieve two primary objectives of aquaculture, *viz*,

(*i*) increasing the individual spawning frequency, and

(*ii*) prolonging the spawning season throughout the year.

Operational procedures for rearing grey mullet larvae from incubation of eggs to the end of the 42 day larval period have been developed by Nash, Kuo and McConnel (1974). The eggs are incubated up to the gastrula stage at high density for 12 h at 22°C. They are washed under stirred irradiated sea water 32 ‰ salinity), then given a one-minute bath in sea water containing the antibiotics potassium penicillin (80 IU/ml) and streptomycin sulphate (0·05 mg/ml) and distributed into the rearing kreisels (circular rearing tanks) at 250 eggs/l. Incubation is then continued for the remaining 24 h. Continuous circulating motion in the kreisel keeps all the eggs in suspension. Both penicillin (10 IU/ml) and streptomycin (0·01 mg/ml) are added daily to control marine bacteria. The larvae begin to feed on the third day and are provided with cultured plankton and rotifers supplemented with available natural plankton. *Artemia* nauplii are provided on the seventh day.

Survival has been increased in the early larval stages by increasing the size of the rearing kreisel and increasing aeration and circulation. Nash, Kuo and McConnel (1974) believe that the survival could possibly be increased further by using even larger units. While light control is desired throughout the entire larval rearing period, exposure of the larvae to direct sunlight during the first five days is lethal and artifical lights are therefore preferred.

Ingestion of empty cysts or shells of *Artemia* causes heavy mortality of larvae up to four weeks of age. The larvae are also susceptible to attacks from the ectoparasites and predators introduced with the natural plankton, and amphipods have been observed attacking even six-week old larvae causing their death.

While considerable progress has been achieved in mullet breeding, the techniques of rearing breeders to full maturity in ponds, the proper dosages of pituitary extract to be used and methods of hatching and rearing, especially determination of the right kind of food for hatchlings and young fry, need to be studied further before the hypophysation technique can be successfully applied for mass production of mullet seed.

3.2 *Production of milkfish seed*

The milkfish (*Chanos chanos*), though widely distributed in the offshore waters of the Indian and Pacific Oceans, is extensively cultured only in the brackishwater ponds of the Indo-Pacific region. Like the mullets, it is suitable for culture in both fresh and brackishwater ponds. However, unlike mullet it does not attain maturity in fresh or brackishwater ponds. It is believed that it spawns in coastal waters and the young ones are collected in large quantities from foreshore areas to stock the ponds. The sites selected for collection are sandy and flat with clear water. Locations near the mouths of small rivers flowing into the sea are best.

Different methods are used in different countries to collect the young larvae, but all operations from collection and transport to its marketing are undertaken by expert fishermen and traders. The milkfish fry industry has perhaps the same status in Indonesia and the Philippines as the carp fry industry in India and China.

In Indonesia, milkfish fry (15–25 mm) are usually collected during high tides from March to May and from September to December, when the sea is not rough. Fry (10–13 mm) of milkfish are available on the Philippines coast from March to August and collected by dipnets in narrow tidal streams, where they are highly concentrated at the peak of the season.

Although the milkfish culture industry in Taiwan Province of China is of recent origin, it is much more productive than that of Indonesia and the Philippines. The fry are collected during spring tides on full and new moons in April and May by using triangular dipnets. A bag seine of varying length, with an opening at the top of the bag for periodical removal of the fry, is also used effectively in deep waters where it is pulled by two men or anchored, where the current is strong, with its mouth facing the current (Lin, 1968).

Availability of seed is the most important problem of the milkfish culture industry in the entire region, the supply from natural sources is upredictable and marked by wide fluctuations. The depletion of fish seed in open waters is aggravated by water pollution from the discharge of industrial wastes (Blanco, 1972). Considering the difficulty in collecting mature breeders from the sea and keeping them alive for induced breeding, it appears necessary to bring about maturity in pond-reared fish. Attempts to breed milkfish artificially are under way on a large scale in the three major producing countries, and it is reported that ovulation of pond-grown milkfish has recently been achieved in Hawaii. Initial success in induced breeding, including the fertilization and hatching of eggs, has recently been reported from the Philippines.

3.3 *Production of yellowtail seed*

The yellowtail (*Seriola quinqueradiata*) cultured in Japan spawns off southern Kyushu in late April or early May. The larvae (about 15 mm) are brought ashore by the Kuroshio current where they are caught in floating seaweeds by fine-meshed encircling nets.

The fry are graded immediately into small, medium and large categories, otherwise serious mortality results from cannibalism (Furukawa, 1972). The graded fry are stocked in nylon net cages for rearing. In natural conditions, they begin to feed when they are four days old: 20–30 mm fry feed on fish eggs and arthropod larvae found amongst floating seaweeds and 40–50 mm fry feed on the larvae of other fish (Tanaka, 1972). In net cages, however, the fry are fed on minced fish and/or shrimp. Feeding on anchovies resulted in 100% mortality as the fry could not digest the unsaturated fatty acids of these oily fish (Bardach, Ryther and McLarney, 1972).

Yellowtail eggs have been raised experimentally but most of the fry used for aquaculture are caught from nature (Tanaka, 1972).

4 Conclusions

In spite of the many advances made in the methods of fish seed production and distribution, these remain as major constraints on the expansion of fish culture. It has not yet been possible to arrange a supply of adequate numbers of pituitary glands for breeding. It would, therefore, be better to find a chemical substitute with a standard potency. Much remains to be known about recognizing the stage of maturity of fish, from either external morphology or the size of

the egg, to determine the dosages to be injected. Methods of inducing 'natural' spawning through hypophysation in Chinese carps have yet to be devised. Methods to bring about proper gonadal development and early maturity or alternatively to reduce the fat content should be studied and techniques of raising fish separately for breeding and for consumption, as in poultry production, need development.

Production of milkfish and prawn seed on a commercial scale is likely to remain a problem until these species can be grown to sexual maturity under controlled conditions. As it is, collection of milkfish spawners and keeping them alive for induced breeding itself forms a major problem. Non-availability of efficient and cheap feeds for mullet larvae are other important problems hampering large-scale production.

Since fish culture also aims at improving the product, selective breeding and hybridization for obtaining all-male or all-female broods, and varieties of seed resistant to fluctuations in the environment need to be developed. Continued research is also required on the diseases affecting the egg, larval and fry stages of almost all species.

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Enhancing Production of Indian Major Carp Fry and Fingerlings by Use of Growth-Promoting Substances

P. R. Sen and D. K. Chatterjee

Abstract

Laboratory and yard experiments were first conducted during the year 1968-69 to observe the effect of 15 different growth-promoting substances in enhancing the survival and growth of rohu (*Labeo rohita*) fry. The results of these experiments indicated that four treatments significantly enhanced survival at the 5% level of confidence: cobalt chloride at 0·01 mg, starch at 3·44 mg, boron at 1·0 mg and manganese at 0·01 mg/day/fish. In addition to these, yeast at 1·0 mg, molybdenum at 0·05 mg and enterocycline at 0·01 mg/day/fish were also found useful.

Field experiments carried out from 1969 to 1972 with Indian major carp fry and fingerlings confirmed the above findings. In 1970, 1971 and 1972 the effect of cobalt chloride on rohu spawn reared in 0·04 ha ponds showed that the percentage of survival over control was 26·90, 7·80 and 17·00. Work in 1969-70 and 1970-71 with fingerling rohu, catla (*Catla catla*), and mrigal (*Cirrhinus mrigala*) showed that the overall percentage of survival with cobalt chloride treatment was 8·40 and 24·0 over the controls respectively from two experiments in two successive years. In the field experiments, starch was also found to be useful.

Stimulation de la production d'alevins de carpe indienne au moyen de substances favorables à la croissance

Résumé

Des expériences de laboratoire et de terrain ont tout d'abord (1968-69) eu pour objet d'observer les effets de 15 stimulants différents sur la survie et la croissance d'alevins de rohu (*Labeo rohita*). Les résultats de ces expériences ont indiqué que quatre traitements ont notablement accru la survie des poissons au taux de confiance de 5%: le chlorure de cobalt, l'amidon, le bore et le manganèse aux concentrations respectives de 0,01 mg, 3,44 mg, 1,0 mg et 0,01 mg par poisson/jour. En outre, la levure, le molybdène et l'enterocycline aux concentrations respectives de 1,0 mg, 0,05 mg et 0,01 mg par poisson/jour se sont également révélés utiles.

Des expériences menées de 1969 à 1972 en milieu naturel sur des alevins de carpe indienne ont confirmé les conclusions susmentionnées. En 1970, 1971 et 1972, l'étude des effets du chlorure de cobalt sur du frai de *Labeo rohita* élevé en étangs de 0,04 ha a montré que le taux de survie excédait celui des témoins dans la proportion de 26,90, 7,80 et 17,00%. Des travaux effectués en 1969-70 et en 1970-71 sur des alevins de *Labeo rohita*, de *Catla catla* et de *Cirrhinus mrigala* ont indiqué que le taux global de survie après un traitement par le chlorure de cobalt excédait celui des témoins de 8,40 et de 24,0% à l'issue de deux expériences faites lors de deux années successives. Dans des expériences en milieu naturel, on a également montré que l'amidon joue un rôle utile.

Aumento de la producción de alevines y jaramugos de las principales carpas indias utilizando sustancias que favorecen el crecimiento

Extracto

Durante los años 1968-69 se realizaron primeramente experimentos en laboratorio y al aire libre para observar los efectos en la supervivencia y crecimiento de jaramugos de rohu (*Labeo rohita*) de 15 sustancias favorecedoras del crecimento. Los resultados de esos experimentos indicaron, con un nivel de fiabilidad del 5%, que cuatro de los tratamientos habían mejorado significativamente la supervivencia: cloruro de cobalto (0,01 mg por día/pez), almidon (3,44 mg), boro (1,0 mg) y manganeso (0,01 mg). También resultaron útiles la levadura (1,0 mg por día/pez), el molibdeno (0,05 mg) y la enterociclina (0,01 mg).

Los experimentos realizados directamente sobre el terreno desde 1961 a 1972 con alevines y jaramugos de las principales carpas indias

confirmaron esos resultados. En 1970, 1971 y 1972, empleando cloruro de cobalto para la cría de rohu en estanques de 0.04 ha, se registró un índice de supervivencia superior al de los testigos en 26,90, 7,80 y 17,00%. Los trabajos realizados en 1969–70 y 1970–71 con jaramugos de rohu, catla (*Catla catla*) y mrigal (*Cirrhinus mrigala*) revelaron, en los peces tratados con cloruro de cobalto, un índice total de supervivencia mayor en 8,40 y 24,0% que el de los testigos. En los experimentos realizados sobre el terreno resultó también útil el almidón.

1 Introduction

Research has shown that the growth of common carp (*Cyprinus carpio*) declines sharply when the component of natural food in the daily ration is less than 17–20% (Sukhoverkhov, 1967). To increase fish production, the production of natural pond food has to be increased proportionately. But the capacity of a pond to produce natural food has its own limitations. After the natural pond food is exhausted, the fish must be provided with supplementary feed; otherwise their survival rate will be low.

Nutrition plays an especially important role under conditions of dense stocking. When the natural food supply declines, the artificial feed provided should be physiologically balanced and rich in organic substances (protein, carbohydrate, fat, *etc*) and should also contain minerals and growth-stimulating substances. Das (1959, 1960, 1967) and Das and Krishnamurthy (1959) have observed that minute quantities of vitamin B-complex and yeast significantly enhance the survival of post-embryonic Indian carp.

In the USSR, Korneeva (1963) and Leonov (1963) have used amino acids, vitamins, cobalt chloride and cobalt nitrate for enhancement and stimulation of growth in carp and salmon. Pickford and Atz (1957) have reported that the normal body growth in fish can be augmented by administration of growth hormone. Sen (1972) also observed that the survival and growth of Indian carp fry can be enhanced significantly by treatment with cobalt chloride and to a lesser extent with starch, boron and manganese. The work reported hereunder deals with the effect of growth promoting substances on survival and growth of fry and fingerlings of Indian major carps.

2 Methods and materials

2.1 *Laboratory experiments with rohu fry*

Four successive sets of laboratory experiments were carried out in 1968–69 for a preliminary screening of 15 growth-promoting substances (Table I).

In each set of experiments, three-day old rohu (*Labeo rohita*) were reared in glass jars containing nine litres of tap water. (Use of tap water helped eliminate the introduction of extraneous food.) Water temperatures during the experiments ranged from 29° to 33°C.

Fifty fry were placed in each jar. They were reared for 15 days, and provided with powdered mustard oil cake plus rice polish in a 1:1 ratio by weight. The quantity of feed given was four times the initial weight of the fish. Growth promoting substances in finely powdered state were mixed with the feed, which was hand pelleted and fed daily. The number of replicates was three or four for each dose of substance tried and a minimum of three different doses was tried at the time of screening. The water was partially replaced with tap water every alternate day after removal of waste water.

The data on growth and survival of fry recorded for each dose of a treatment were pooled and analysed, and the results compared with the respective controls. The micronutrients that indicated the most promising results in this preliminary screening were subsequently given further trials. See section 3.1 for results.

TABLE I
THE 15 GROWTH PROMOTING SUBSTANCES USED FOR PRELIMINARY SCREENING

Substances	*Preparations*
Proloid	A biological standardized thyroglobin preparation Martin and Harris (P) Ltd
Eltroxin	L-thyroxin sodium, Glaxo Laboratories (P) Ltd
Berin	Aneurin hydrochloride, BP, Glaxo Laboratories (P) Ltd.
Macrabin	Vitamin B_{12} Glaxo Laboratories (P) Ltd
Vitamin B Complex	Vitamin B_{12}, Vitamin B_1, Riboflavin BP, nicotinamide, calcium pantothenate and Vitamin B_6, BP, Glaxo Laboratories (P) Ltd.
Yeast	Squibb brewer's yeast, Sarabhai Chemicals (P) Ltd.
Starch	Weikfield's laundry starch powder
Selenium	A micronutrient, used as selenium dioxide.
Molybdenum	A micronutrient, used as sodium molybdate
Boron	A micronutrient, used as boric acid powder.
Cobalt chloride	A micronutrient analytical quality, BDH Ltd.
Enterocycline	Chemotherapeutic agents, tetracycline. Dey's Medical Stores (P) Ltd
Chloromycetin	Chloramphenicol, Parke Davis (P) Ltd.
Hoestacycline	Terramycin + Chloramphenicol, Hoechest (P) Ltd.
Manganese	A micronutrient, used as manganese sulphate

The fifteen growth-promoting substances were initially tried during the year 1968–69 with respect to the following qualities: (*i*) effect on survival and growth of fish, (*ii*) their ease of application, (*iii*) cost, (*iv*) effect with small dosage, (*v*) side effects, if any, and (*vi*) their consistency.

The dosages tried in the present study were based mainly on the potency, economy and ease of handling of the substances.

2.2 *Yard experiments with rohu fry*

Those substances that gave significant results in so far as the final percentages of survival and growth of fry were concerned, were given yard trials in plastic pools with rohu spawn. Manganese was, however, not given further trials. As in the laboratory experiments, during the period of study the water temperature ranged between 29° and 33°C. See section 3.2 for results.

2.3 *Field experiments with fry and fingerlings*

At the conclusion of the laboratory and yard experiments, the selected growth-promoting substances were given further trials in the field. These trials were made from 1969 to 1972 in 0·04 ha ponds at Killa Fish Farm, Cuttack. The ponds averaged 1·5 m in depth, were more or less uniform ecologically, and were not manured. During the course of the experiments the water temperature ranged from 27° to 32°C.

2.3.1 *Field trials with rohu fry.* Three sets of field trials were made with rohu fry. In the first set (1970) the ponds were stocked with rohu spawn at a density of 2·5 million/ha and reared for 13 days. In one of the ponds, the fish were supplied with cobalt chloride at the rate of 0·01 mg/day/

fish along with supplementary feed of finely powdered ground nut oil cake and rice polish. The other pond, where only supplementary feed was provided, served as a control. The fish were fed once a day, the feed being broadcast on the surface (Table II).

The second and third sets of field trials with rohu fry were conducted during 1971 and 1972. The experimental procedure remained identical with that in the first trial except that the stocking densities were raised to 3·75 million/ha and 6·25 million/ha respectively. In both years, three ponds received cobalt chloride (at 0·01 mg/day/fish) along with the supplementary feed (Table II), and two ponds where only feed was provided, were kept as controls.

On the fourteenth day of all trials, the fry from all the ponds were harvested and survival and their growth re corded. See section 3.3 for results.

TABLE II
FEEDING SCHEDULE OF FRY AND FINGERLINGS IN FIELD TRIALS IN 0·04 HA PONDS, 1969–71[1]

	Duration	*Rate of feeding/day/pond*
Fry (rohu)	First five days	Four times more feed than the initial weight of all fry stocked
	Next seven days	Eight times more feed than the initial weight of all fry stocked
	Thirteenth day	No feed given
	Fourteenth day	Harvesting.
Fingerlings (rohu, catla, mrigal)	First month	750 g
	Second, third and fourth month	1000 g

[1] Daily ration: ground nut oil cake and rice polish (1:1)

2.3.2 *Field trials with rohu, catla and mrigal fingerlings.* During the years 1969–70 and 1970–71, trials were con ducted with fingerlings of rohu, catla (*Catla catla*), and mrigal (*Cirrhinus mrigala*). Four 0·04 ha ponds were used The stocking density was 6 000/ha and the species ratio was catla 1: rohu 1: mrigal 1. In 1969–70, three ponds received feed along with cobalt chloride (at 0·01 mg/day/fish), starch (at 3·44 mg/day/fish) and boron (at 1·0 mg/day/fish) respectively and one pond was kept as a control. A similar type of experiment was carried out in 1970–71 with cobalt chloride and starch, but instead of boron a trial was made with manganese (at 0·01 mg/day/fish) based on the previous result. The feeding schedule is indicated in Table II.

Observations on water quality in these ponds were made bi-weekly and on soil condition at the beginning and end of the experiment. Initial and final samples of plankton were also collected and analysed by filtering 45 litres of pond water. See section 3.4 for results.

3 Results and discussion

3.1 *Laboratory experiments*

The results of the initial (*ie* laboratory) experiments with rohu fry to screen growth promoting substances are shown in Tables III and IV.

The best performances with regard to survival and weight increments of rohu fry over control in sets I–III were with starch (13·92 and 57·99), boron (130·98 and 43·00) and cobalt chloride (50·15 and 24·44) at a dose of 3·44 mg, 1·0 mg and 0·01 mg/day/fish respectively (Table III). In set IV of the experiments the performance of manganese was best when supplied at 1·0 mg/day/fish. However, the performance of this substance at 1·0 mg and 0·01 mg/day/fish did not vary significantly, hence the lower dose was considered (Table III).

The mean values of percentage survival of a particular dose of each substance which proved superior to the control in different sets were subjected to 't' test. Starch (3·44 mg), boron (1·0 mg), cobalt chloride (0·01 mg) and manganese (0·01 mg) indicated significant difference at the 5% confidence level over their respective critical difference values (Table IV).

3.2 *Yard experiments*

The results of the set of experiments conducted with rohu fry in plastic pools to determine the relative usefuless of the substances screened from the laboratory experiments are shown in Table V. An analysis of co-variance worked out on the final proportions on survival and growth of these experimental units is also shown in Table V. The final survival percentage and growth between the different experimental treatments differed significantly at the 5% level. Hence the differences were computed between the means of each dose of treatments and control (Table V)

The results of the plastic pool experiment showed that treatment with cobalt chloride at 0·01 mg/day/fish was most satisfactory, followed by boron at 1·0 mg/day/fish and starch at 3·44 mg/day/fish.

3.3 *Field experiments*

3.3.1 *Trials with fry.* The work in 1970, 1971 and 1972 showed that the increase in percentages of survival in the ponds with rohu spawn receiving cobalt chloride were 26·90, 7·80 and 17·00 respectively which were very sig nificant (Table VI). Even in the presence of an adequate food supply and the absence of predators, density by itself affected survival. The results with cobalt chloride treatment indicated that even at an early stage it was possible to enhance survival and reduce the effect of density.

During the early period of growth, the spawn or fry are in a state of physiological susceptibility to factors adversely affecting survival, depending upon density. By introducing a state of balance by the use of micronutrients, it may render the spawn or fry more resistant to such factors. Without treatment such resistance may come only with advanced age. Sukhoverkhov (1967) has noted that the application of cobalt chloride along with the feed increased food demand of common carp (*Cyprinus carpio*). He further stated that cobalt chloride, a part of Vitamin B_{12} and of primary importance in the formation of erythrocytes and the synthesis of haemoglobin, is essential for normal activity of the fish. He also stated that cobalt greatly affects fermentation intensifying the synthesis of muscular protein and assimilation of nitrogen.

From Table V it was found that the difference between treatment's effect was significant at the 5% level. By testing the significance of differences between pairs of adjusted treatment means, it was found that the minimum significant difference at the 5% level was 0·00257 where the standard error of mean of difference – 0·001.

3.3.2 *Trials with fingerlings.* In the 1969–70 and 1970–71 experiments with fingerlings of catla, rohu and mrigal in

TABLE III

LABORATORY EXPERIMENTS WITH ROHU FRY USING DIFFERENT GROWTH PROMOTING SUBSTANCES, 1968–69[1]

Set No.	Substances	Dose/day/fish (mg)	Mean % survival over control	Mean % length increment over control	Mean % weight increment over control
I	Proloid	0·01	11·39	11·43	−39·77
		0·02	13·29	1·68	3·53
		0·04	−5·06	3·30	−31·97
	Eltroxin	0·025	10·12	−9·38	−38·47
		0·005	3·16	1·68	40·33
		0·001	−25·31	−10·40	38·28
	Berin	0·125	10·12	4·57	36·98
		0·25	10·12	−4·63	5·94
		0·5	−16·45	−1·38	−26·76
	Macrabin	0·125	2·53	−7·09	−41·07
		0·25	−26·58	4·69	25·09
		0·5	13·92	3·24	17·84
	B-Complex	0·1012	5·06	−7·46	63·19
		0·21	−6·32	6·13	4·08
		0·405	20·88	5·47	−5·20
	Yeast	0·5	−22·78	0·66	−20·44
		1·0	11·39	5·29	28·25
		2·0	−19·62	3·18	−9·85
	Starch	1·72	1·26	6·43	−0·92
		3·44	13·92	3·30	57·99[2]
		6·88	5·06	1·26	−15·98
II	Selenium	0·05	−30·6	2·16	25·9
		0·5	32·5	8·97	36·78
		1·0	4·29	1·82	16·06
	Molybdenum	0·05	47·23	2·07	20·20
		0·5	24·54	−2·99	11·90
		1·0	22·69	4·90	37·82
	Boron	0·05	22·69	10·31	35·75
		0·5	36·8	9·22	51·29
		1·0	130·98	7·23	43·00[2]
III	Cobalt chloride	0·01	50·15	9·22	24·44[2]
		0·02	50·15	1·80	2·22
		0·03	43·76	0·21	8·88
	Entrocycline	0·01	49·04	1·80	6·66
		0·02	52·23	1·08	6·66
		0·03	37·38	2·96	13·33
IV	Hoestacycline	0·01	8·0	−17·14	24·48
		0·02	6·78	18·33	−21·35
		0·03	9·56	19·27	−25·72
	Chloromycetin	0·01	13·91	−16·79	25·61
		0·02	16·52	19·72	−33·43
		0·03	19·82	−16·15	20·29
	Manganese	0·01	65·73	−13·62	36·51[2]
		0·05	62·26	−13·23	38·51
		0·5	69·29	11·34	−39·14
		1·0	64·69	−13·62	37·87

[1] In each experiment 50 rohu fry were held in a glass jar for 15 days.

[2] Selected for further trials

TABLE IV

FINAL PROPORTIONS OF ROHU FRY SURVIVING, AND DIFFERENCES BETWEEN TREATMENT AND CONTROL MEANS IN LABORATORY TRIALS, 1968–69

Set No.	Substances	No. of fry stocked	Mean proportion surviving	Difference of means from control	Significance of difference between means
I	Proloid	50	0·88	0·090	P < 0·05
	Eltroxin	50	0·82	0·030	P < 0·05
	Berin	50	0·87	0·080	P < 0·05
	Macrabin	50	0·81	0·020	P > 0·05
	B Complex	50	0·83	0·040	P < 0·05
	Yeast	50	0·88	0·090	P > 0·05
	Starch	50	0·90	0·110	P < 0·05
	Control	50	0·79		
			P < 0·05 as 5% critical difference 0·092		
II	Selenium	50	0·34	0·010	P < 0·05
	Molybdenum	50	0·48	0·150	P > 0·05
	Boron	50	0·75	0·420	P < 0·05
	Control	50	0·33		
			P < 0·05 as 5% critical difference 0·195		
III	Cobalt chloride	50	0·94	0·310	P < 0·05
	Entrocycline	50	0·93	0·300	P < 0·05
	Control	50	0·63		
			P < 0·05 as 5% critical difference 0·205		
IV	Manganese	50	0·95	0·370	P < 0·05
	Hoestacycline	50	0·62	0·040	P > 0·05
	Chloromycetin	50	0·59	0·010	P > 0·05
	Control	50	0·58		
			P < 0·05 as 5% critical difference 0·138		

TABLE V

YARD (PLASTIC POOL) EXPERIMENTS WITH ROHU FRY USING DIFFERENT GROWTH-PROMOTING SUBSTANCES, 1968–69

Substances	*No. of fish reared*	*No. of days reared*	*Dose mg/day/fish*	*% Survival over control*	*% Length increment over control*	*% Weight increment over control*
Cobalt chloride	100	15	0·01	16 81	3·47	13·21
Boron	100	15	1·0	7 75	Nil	6·94
Starch	100	15	3·44	20·11	3·23	Nil

Analysis of covariance on survival and growth

Source of variation	*DF*	Σx^2	Σxy	Σy^2	*byx*	*byx*Σxy	*Sum of squares corrected for regression*	*DF*
Replications	2	240·7	0·070	0·000022		—		—
Treatments	3	361·0	0·032	0·000057	0 000088	0·000003	0 000054	2
Error	6	345·3	0·184	0 000106	0 000532	0·000098	0 000008	5
Treatment + Error	9	706 3	0·216	0·000113	0 000306	0 000066	0·000047	8
Total	11	947·0	0·146	0·000135				

Test for significance of treatment effects

Source of variation	*DF*	*Sum of square*	*Mean sum of square*	*F (Variance ratio)*	*F at 5% point*
Treatment + Error	8	0 000066			
Error	5	0 000008	0·000002	9 5	5·41
Difference	3	0·000058	0·000019		

x – Survival rate
y Growth
byx Regression coefficient
DF Degree of freedom

Σx^2 Sum of squares of independent variable x
Σy^2 Sum of squares of dependent variable y
Σxy Sum of products

TABLE VI

FIELD EXPERIMENTS WITH ROHU FRY SHOWING THE SURVIVAL AND PRODUCTION OF FRY IN 14 DAYS USING COBALT CHLORIDE

	Treatment					
	Cobalt chloride			*None (Control)*		
	1970	*1971*	*1972*	*1970*	*1971*	*1972*
Stocking density in million/ha	2 5	3·75	6 25	2·5	3 75	6·25
Average survival (%)	87 3	73·6	62 0	60·4	65 8	45·0
Length, net increment (mm)	14 67	16·15	21 3	17·21	14·45	22 7
Weight, net increment (mg)	113·5	127·47	112·46	147·5	91 76	112·58
Fry production in million/ha	2 2	2·7	3·9	1·5	2·5	2 8

0·04 ha ponds, the survival percentage of fingerlings after four months of rearing was fairly high. The aggregate survival percentages of the three species of carp in the ponds treated with cobalt chloride were recorded at 8·40 and 24·00 over the controls, which was significant (Table VII). The net increments in production over the control were 244·94 kg and 391·95 kg respectively in the two experiments. In other words, the treatment helped in stepping up production by 49·06 and 128·96% over control.

Tomantik and Batyr (1965) reported that carp fingerlings fed with cobalt nitrate at a level of 0·08 mg/day/fish had an enhanced survival rate 16·1% above that in the control and that this was significant and thus helped to increase production by 166 kg over control.

The experiments reported herein have revealed that cobalt treatment resulted in the best survival and growth of all the three species of carps.

Catla, rohu and mrigal fingerlings when treated with starch exhibited aggregate survival percentage increases of 11·32 in the first year and 17·08 in the second year over the controls which was also significant (Table VII). The treatment with starch in the two sets of experiments conducted in successive years enhanced the net production by 171·69 kg and 242·47 kg (*ie*, 34·39% and 79·66% increase) over the controls. Cerney (1961) has reported a similar increment in the natural growth of carp in a pond fed with starch.

The performance of catla, rohu and mrigal with boron and manganese was not as satisfactory as with cobalt and starch, although their nutritional significance has already been established in animal physiology. The treatment with boron and manganese no doubt helped in the net increase in production by 105·85 kg and 106·84 kg respectively over

TABLE VII

FIELD EXPERIMENTS ON THE SURVIVAL AND PRODUCTION OF THREE SPECIES OF CARP FINGERLINGS IN 4 MONTHS WHILE USING GROWTH PROMOTING SUBSTANCES

Type of treatment	*Species*	*Weight (g)*		*Yield (kg/ha)*		*Aggregate production (kg/ha)*		*% increment in production over control*	*Survival %*	*Aggregate survival %*	*% increment in survival over control*
		Initial	*Final*	*Gross*	*Net*	*Gross*	*Net*				
1969–70											
Control	Catla	42·50	153·9	246 25	178 24	647·25	499·21	—	82·0	82·85	—
	Rohu	29·37	126·08	230·0	194 75				91·25		
	Mrigal	15·0	99·15	171·0	126·23				75·0		
Cobalt Chloride	Catla	42·50	207·05	403·75	320·87	907 75	744 15	49·06	97 50	91·25	8·4
	Rohu	29·37	172·66	336 50	279 42				97·50		
	Mrigal	15·0	106·34	167 50	143 86				78·75		
Boron	Catla	42·50	189·0	283 50	219·75	773·56	605·06	21·2	75·0	85 83	2 98
	Rohu	29·37	155·47	303 25	245 90				97·50		
	Mrigal	15·0	97·01	186 75	139 42				85·0		
Starch	Catla	42·50	188·60	372 50	288 55	849·50	670·90	34·39	98·75	94 17	11 32
	Rohu	29·37	149·36	300 0	239 98				100·0		
	Mrigal	15 0	100·0	177·0	142 38				83·75		
1970–71											
Control	Catla	52·50	129·0	183 75	109 01	394 0	304·35	—	71 25	74 58	
	Rohu	3·12	80·0	104 0	99 94				65 0		
	Mrigal	6·20	60·71	106 25	95·39				87 50		
Cobalt Chloride	Catla	52·50	214·0	422 25	318 96	841·80	696·30	128·78	98·75	98 58	24·0
	Rohu	3·12	101·66	202 50	197 16				100·0		
	Mrigal	6·20	98·60	217 05	180 18				97·50		
Starch	Catla	58·60	189·40	378 75	261 60	681·25	546·82	79 66	100·0	91·66	17·08
	Rohu	3 12	93·20	141·25	135·12				75 0		
	Mrigal	6 20	81 25	162·50	150·10				100·0		
Manganese	Catla	95·10	199·34	378 75	198 06	615·25	411·19	35 11	95·0	73·33	−1 25
	Rohu	3·12	90·35	138 50	122·05				70·0		
	Mrigal	6 20	89 0	98·0	91·08				55 0		

[1] Stocking density 6 000 fish/ha of equal numbers of catla, rohu and mrigal

control. Banerjea and Banerjee (1967) opined that the application of manganese as a trace element helped in the production of plankton by about 14% more than the control. Seekles (1950) has reported that in young mice and other higher vertebrates kept on a manganese deficient diet, growth was stunted, ovulation discontinued and heat seldom occurred. With boron the production was enhanced 21% and with manganese it was 35·11% which also was found to be significant but to a lesser extent.

3.4 *Effect of the treatments on water quality, soil condition and plankton*

The pond water used in the field experiments had an initial pH range of 7·3 8·4 with high total alkalinity (101- 145 ppm). Most of the ponds showed higher concentration of dissolved phosphorus and low $NH_3 + NO_3 - N$ except in 1972 when the condition was the reverse. It is clear from Table VIII that the water qualities of the ponds receiving feed with cobalt chloride did not show much variation from the control except that there was a fall in dissolved phosphorus at the end of the experiment.

The soil condition of the treated ponds showed an increase in available phosphorus and cobalt, whereas a marked fall was noticed in available nitrogen, organic carbon and to some extent pH, at the end of the experiment. The increase in available cobalt was more pronounced except in 1970 as also was the available phosphorus in the treatments.

In fingerling rearing experiments, both the water and the soil condition of the ponds receiving feed mixed with cobalt chloride showed results more or less identical with those recorded in fry rearing except that the dissolved phosphorus and $NH_3 + NO_3$ - N in water phase maintained a higher level both in the initial and final stages. The available phosphorus and cobalt in soil which showed an increase in the final phase of fry rearing, showed a downward trend in the ponds where fingerlings were reared.

Plankton collected from the ponds was found to be negligible in the initial and final samples. Stray zooplankters, namely *Brachionus, Filinia, Polyarthra, Diaptomus, Moina* and *nauplii*, were present.

4 Conclusion

Cobalt chloride at the rate of 0·01 mg/day/fish added to the feed helped to enhance the survival and growth of rohu fry and fingerlings of the Indian major carps: rohu, catla, and mrigal. It also helped to realize a higher production of fingerlings, the maximum being 128·96% over that in the controls.

In the field trials, starch was also found to be useful at the rate of 3·44 mg and to a lesser extent boron when provided at 1·0 mg and manganese at 0·01 mg/day/fish along with the feed.

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TABLE VIII

AVERAGE CHEMICAL CONDITION OF WATER AND SOIL IN THE PONDS USED IN THE EXPERIMENTS WITH INDIAN CARP[1]

Year	Treatment	Pond No.	Water Quality									Soil Condition										
			Initial				Final					Initial				Final						
			pH	Total Alk.	P_2O_5	NH_3+ NO_3N	pH	Total Alk	P_2O_5	NH_3+ NO_3N	pH	Av. N	Av. P_2O_5	Org. C%	Co	B	pH	Av N	Av P_2O_5	Org. C%	Co	B
Fry Rearing																						
1970	Control	1	8·4	101	0·16	0·02	7·5	122	0·20	0 06	6·8	98	140	0 284	1·50	—	6 8	109	160	0·213	1·0	—
	Cobalt Chloride	2	8 1	112	0·48	0·10	8 6	105	0 12	0 02	6·9	289	120	0·788	0·75	—	6·6	243	180	0·683	0·75	—
1971	Control	1	7·6	106	0·06	Tr	7·5	128	0·50	0·01	6 2	269	160	0·433	2·0	—	6·2	262	180	0·348	1 43	—
	Cobalt Chloride	2	7·4	132	1 0	0 03	7·4	128	0 06	0·07	6·8	333	200	0·895	0 45	—	6·6	240	240	0·733	1·69	—
	Cobalt Chloride	3	7·3	141	0 32	0·02	7 8	141	0 38	0·01	6·2	288	160	0·694	0·45	—	6·2	211	180	0 417	1·45	—
	Cobalt Chloride	4	7·5	145	1·20	Tr.	7 5	132	0·50	0 01	6·4	295	180	0·741	0·12	—	6·2	225	180	0·433	2·0	—
1972	Control	1	7·6	132	0·14	0 16	8·3	140	0·24	0·02	6·4	210	140	0·396	0·79	—	6·4	201	180	0·280	1·0	—
	Cobalt Chloride	2	7 4	109	0·02	0·50	8·4	106	0·08	0 02	6 6	318	140	0 700	0·88	—	6·6	204	220	0·486	2 5	—
	Cobalt Chloride	3	7·6	132	0·06	0·70	8·4	126	0·08	Tr.	6·6	262	120	0 298	0 41	—	6 4	219	200	0 288	2·25	—
	Cobalt Chloride	4	7·4	109	Tr	0 40	8·1	78	0·08	0·04	6·4	232	110	0·247	0·12	—	6·2	171	220	0·141	1·50	—
Fingerling Rearing																						
1969–'70	Control	1	7·8	128	0·68	0·65	7 8	158	0·61	0 77	6·6	300	300	0·713	2·0	0·70	6·5	271	400	0·512	2·0	0·86
	Boron	2	7·6	124	0 53	0·62	8 3	130	0·33	1 05	6 2	331	140	0 889	—	0·82	6·0	323	180	0·713	—	1·70
	Cobalt Chloride	3	8·2	124	0 67	0·77	8 5	120	0·38	0·66	6·2	265	120	0·86	1 5	—	6 0	259	120	0·772	1·0	—
	Starch	4	7·9	132	0 80	0·77	7 8	158	0·61	0 77	6·6	288	320	0·807	—	—	6·8	279	200	0 712	—	—
1970–'71	Control	1	8·0	92	0 26	0 55	8 2	157	0 52	0 85	6 5	152	80	0·189	1·0	—	6·4	177	120	0·133	1·0	—
	Cobalt Chloride	3	7·8	106	0 24	0·35	7 9	168	0 69	0·55	6·6	164	80	0 186	1·75	—	6 4	182	80	0·155	1·0	—
	Starch	4	8 6	92	0·32	0 50	8 3	165	0 58	0·43	6·8	163	300	0·217	—	—	7 0	134	160	0·202	—	—
	Manganese	5	8 2	132	0·34	0 03	8 1	163	0 57	0·30	6·6	234	400	0·302	—	—	6 6	217	300	0·279	—	—

[1] Expressed as %, except pH

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Preservation of Trout Spermatozoa for Varying Periods

W. Holtz, S. Büyükhatipoglu, J. Stoss, B. Oldigs and H. J. Langholz

Abstract

The preservation of trout spermatozoa for extended periods of time has advantages in trout breeding similar to those in semen freezing in breeding certain domestic animals.

In considering the process of preserving trout spermatozoa, the development of a suitable semen diluent was considered an important first step. Unlike most previous investigators who used media based on the composition of blood of fish, a semen diluent was developed on the basis of the organic and inorganic constituents in trout seminal plasma.

Preliminary experiments to determine the most suitable method for storage of spermatozoa indicated that (*i*) the most favourable method was to store sperm undiluted in a moisture saturated atmosphere of air at 1 °C in the dark; (*ii*) carbon dioxide is completely unsuitable as a gas medium for semen storage, and (*iii*) nitrogen gas is better than carbon dioxide, but still considerably less suitable than air.

In semen freezing trials, results obtained in terms of post thaw motilities indicated that, (*i*) samples frozen as pellets gave higher motility than when frozen in mini straws; (*ii*) DMSO was a better additive than glycerol for prevention of cell damage during freezing and thawing, and (*iii*) soybean protein was better than bovine serum albumin or egg yolk as a protein source.

Préservation des spermatozoïdes de truite pendant des périodes de durée variable

Résumé

La preservation des spermatozoïdes de truite pendant des periodes prolongees présente pour l'élevage trutticole des avantages analogues a ceux que procure la congélation du sperme de certains animaux domestiques.

Durant l'examen du procedé de preservation des spermatozoïdes de truite, on a considéré que la mise au point d'un diluant adéquat du sperme constituait une première etape importante. Alors que la plupart des chercheurs précédents utilisaient un milieu basé sur la composition du sang de poisson, les spécialistes ont mis au point un diluant du sperme composé des constituants organiques et inorganiques du plasma séminal de la truite.

Des expériences préliminaires visant à déterminer la methode la plus appropriée d'entreposage des spermatozoïdes ont fourni les indications ci-apres: (*i*) la méthode la plus favorable consistait a entreposer du sperme non dilue a l'abri de la lumière dans une atmosphère saturée d'humidité à une température de 4°C; (*ii*) le gaz carbonique ne convient absolument pas comme milieu gazeux pour l'entreposage du sperme; (*iii*) l'azote gazeux convient mieux que le gaz carbonique, mais reste nettement inférieur à l'air.

Lors d'essais de congélation de sperme, les résultats obtenus en termes de motilite postérieure à la décongelation ont fourni les indications suivantes: (*i*) les echantillons congelés en mini paillettes ont accusé une plus grande motilité que lorsqu'ils étaient congelés en granulés; (*ii*) le DMSO était un additif supérieur au glycérol pour prévenir la deterioration des cellules pendant la congélation et la décongélation; et (*iii*) la protéine de soja était supérieure à l'albumine du sérum bovin ou au jaune d'oeuf comme source de protéines.

Conservación de espermatozoos de trucha por diversos períodos

Extracto

La conservación de espermatozoos de trucha por periodos prolongados de tiempo tiene para la truticultura ventajas análogas a las de la congelación del semen de algunos animales domésticos.

Se considero que, en el proceso de conservacion de los espermatozoos de trucha, uno de los primeros pasos importantes es la preparación de un diluente adecuado para el semen. A diferencia de la mayor parte de los investigadores que se han ocupado antes de esta cuestion, que se servían de medios basados en la composición de la sangre de los peces, se preparo un diluente basado en los constituyentes orgánicos e inorgánicos del plasma seminal de la trucha.

Los primeros experimentos hechos para determinar el metodo más adecuado para almacenar los espermatozoos han indicado: (*i*) el método más favorable consiste en almacenar el esperma sin diluir en atmósfera de aire saturado de humedad a 4 °C en la oscuridad; (*ii*) el dióxido de carbono es totalmente inadecuado como medio gaseoso para el almacenamiento de semen; y (*iii*) el gas nitrógeno es mejor que el dióxido de carbono, pero considerablemente menos adecuado que el aire.

En los ensayos de congelacion de semen los resultados obtenidos por lo que se refiere a la motilidad despues de la descongelacion indican, (*i*) las muestras congeladas en bastoncillos dieron mayor motilidad que las congeladas en gránulos; (*ii*) el dimetilsulfóxido resultó mejor aditivo que el glicerol para impedir los daños a las celulas durante la congelación y la descongelacion, y (*iii*) la proteina de soja resulto mejor como fuente de proteínas que la albúmina de suero de bovinos o la yema de huevo.

1 Introduction

As the worldwide supply of nutritious, palatable protein becomes increasingly valuable, intensive production of edible fish will increase in importance. In this context, control of reproductive processes plays an important part, in particular if seasonal breeders, such as trout, are involved.

The preservation of spermatozoa for extended periods of time, even years, has advantages similar to those in semen freezing in the breeding of certain domestic animals. It also permits the crossing of genetic strains with different spawning seasons, thus allowing for the utilization of hybrid vigour (heterosis) to increase production. There is still, however, a lack of reliable evidence indicating how long and under what conditions trout milt can be kept after collection before it loses its fertilizing ability, and trout breeders have to rely on their own experience and common practice.

For preserving sperm cells obtained from rainbow trout (*Salmo gairdneri*), the development of a suitable semen diluent was considered an important preliminary step. For dilution of trout sperm, most investigators have adopted the so-called Cortland medium or slight modifications thereof. Cortland medium was originally developed on the basis of blood from fish rather than semen, as it was meant to serve

as an *in vitro* culture medium for certain somatic tissues (Wolf, 1963). Since it was recognized that, apart from factors such as osmotic pressure and pH, it is mainly the relationship between certain electrolytes in the suspending medium that is responsible for retention of the ability of spermatozoa to respond with vigorous motility to dilution with water (Stoss, Büyükhatipoglu and Holtz, in preparation), it was decided as a first step to investigate the composition of trout seminal plasma.

2 Methods

Throughout the spawning season, milt was collected systematically from untranquillized two-year-old male rainbow trout at 1-, 2- or 4-week intervals. Semen was centrifuged immediately after collection and seminal plasma was aspirated and stored in liquid nitrogen in tightly capped vials. Upon thawing, analyses were conducted to determine the concentrations of the following organic substances (the source of the technique applied is given in brackets): fructose (Yaphe and Arsenault, 1965); citric acid (Saffran and Denstedt, 1948); glycerylphosphorylcholine (White, 1959); pyruvic acid (Cabaud and Wroblewski, 1958); and lactic acid (Barker and Summerson, 1941).

On a limited number of samples the electrolytes sodium, potassium, calcium and magnesium were determined by atomic absorption spectrophotometry while orthophosphate was measured colorimetrically. Nitrogen was determined by the Kjeldahl method and chloride by a titrimetric procedure.

3 Results and discussion

The results of all analyses are summarized in Table I. As the effects of both season and frequency of collection were not found to be very pronounced, only overall means are given.

On the basis of these results (some of which require confirmation by larger sample numbers), a semen diluent containing 592 mg/100 ml NaCl, 172 mg/100 ml KCl, 78·9 mg/100 ml $CaCl_2$, 30·9 mg/100 ml $MgSO_4$ was developed. In addition, penicillin (100 000 units/100 ml), streptomycin (100 mg/100 ml), Tris (2 420 mg/100 ml) and enough citric acid to obtain a pH of 7·25 were added.

TABLE I
THE MEAN CONCENTRATIONS OF SEVERAL ORGANIC AND INORGANIC CONSTITUENTS IN SEMINAL PLASMA FROM RAINBOW TROUT

Substance	*Number of fish from which semen was analysed*	*Mean concentration*[1] *(mg/100 ml)*
Fructose	84	7·78
Citric acid	84	190 01
Glycerylphosphorylcholine	84	36 23
Pyruvic acid	84	1 92
Lactic acid	84	2·01
Nitrogen	4	12·40
Sodium	9	238·80
Potassium	9	99·00
Calcium	5	5·57
Magnesium	9	2·74
Chloride	3	478·70
Orthophosphate	4	not detectable

[1] All determinations were done in duplicate or triplicate

In order to establish the most suitable way of short-term preservation of trout spermatozoa, freshly collected semen was diluted with the above mentioned extender at semen: extender ratios of 1:0, 1:1 and 1:16. The samples were kept in the dark in a moisture-saturated atmosphere of either air, N_2 or CO_2, at constant room temperature (20–22°C) or at +4°C. Motility estimates were determined at daily intervals as described by Holtz, Stoss and Büyükhatipoglu (in preparation). The results of the experiment, which was replicated eight times, are presented in Table II. Apparently CO_2 is completely unsuited as a gas medium for semen storage. Nitrogen gas was better but still considerably less suitable than air. Room temperature enhanced the rate of decline of sperm motility in comparison to refrigerator temperature. Dilution with an extender has a deleterious effect on sperm motility. In a single trial, trout semen kept for a period of nine days under the condition found to be most favourable for storage (*ie*, undiluted in a moisture-saturated atmosphere of air at 4°C in the dark) was used for fertilization of freshly collected eggs. It turned out that 94·74% of all eggs were fertilized, which compared favourably with the 94·90% obtained when using freshly collected milt for control.

TABLE II
MOTILITY RETENTION TIME FOR RAINBOW TROUT SPERMATOZOA (AFTER DILUTION WITH WATER) STORED UNDER DIFFERENT CONDITIONS

Dilution rate	*Motility retention time (days)*					
	Air		N_2		CO_2	
	20°C	4°C	20°C	4°C	20°	4°C
Undiluted	2	7 11	2	5	0	0
1:1	1	1	0	1	0	0
1·16	0	0	0	0	0	0

In semen freezing trials, the aforementioned dilution medium was added to trout semen at ratios of 1:1 and 1:3. As sources of protein, either bovine serum albumin, egg yolk or a soybean protein were added. Glycerol or DMSO respectively were added at a level of 12% to protect against cell damage during freezing and thawing. The effect of lecithin as an additive to the dilution medium was also investigated. Samples were frozen either in mini-straws (Cassou, 1968) or as pellets (Nagase, 1964) both of which were stored in liquid nitrogen. Results obtained in terms of post-thaw motilities indicated that pellets were better than straws, DMSO was better than glycerol, lecithin had no favourable effect, and soybean protein rendered better results than bovine serum albumin or egg yolk.

Fertility trials comparing several media and processes and including some procedures published in the literature (Hodgins and Ridgway, 1964; Ott and Horton, 1971; Stein, 1975) are being conducted at present. Some limited success (9% of eggs fertilized in comparison to 61% with fresh control semen) has been obtained in a preliminary trial after storage of semen in liquid nitrogen for 25 days.

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The Development of a Nursery Technique for Rearing Turbot *Scophthalmus maximus*, from Metamorphosis to Ongrowing Size —Progress Since 1970 by the British White Fish Authority

P. L. Smith

Abstract

Since 1965, the British White Fish Authority has been developing culture methods for marine flatfish. Using plaice (*Pleuronectes platessa*) as the experimental animal, early trials indicated that intensive cultivation in floating cages was preferable to free ranging in larger areas on a natural substrate. Experimental work progressed to more highly valued species when a small number of wild juvenile turbot (*Scophthalmus maximus*) became available in 1971. The basic husbandry techniques established with plaice had to be changed, especially with regard to feed presentation. To obtain a high growth rate in the cages, the juvenile turbot were held in an onshore nursery over their first winter period of low water temperatures, and grown to a size in excess of 50 g.

Using a nursery unit comprising 20 tanks, each of 1 m^3 volume, supplied with continuously pumped sea water, experiments have been conducted mainly with juvenile turbot of wild origin and, more recently, also of hatchery origin. Experiments with feeding involved initial use of a natural diet of mysid shrimps, followed by use of a wet fish paste and finally a moist composite pellet of white fish meal, filleting offal, soybean derivative and a vitamin/binder mixture. Elevation of the ambient water temperature to between 12° and 15°C has been necessary to achieve adequate growth and survival, depending upon the grade of the stock upon entering the nursery.

The majority of the hatchery produced juveniles were transferred to the nursery at too small a size and consequently suffered higher mortality. It is recommended that in future hatchery stock should achieve a minimum size of 0·5 g before being moved. Hatchery stock were non aggressive and demonstrated superior survival and food conversion after weaning onto an artificial diet when compared with wild stock.

Mise au point d'une technique d'alevinage applicable a l'élevage du turbot (*Scophthalmus maximus*) depuis la métamorphose jusqu'aux tailles juvéniles—progres réalisés depuis 1970 par la British White Fish Authority

Résumé

Depuis 1965, la British White Fish Authority s'efforce de mettre au point des méthodes d'élevage de pleuronectidés marins. Les premières expériences réalisées sur la plie (*Pleuronectes platessa*), ont montré que l'élevage intensif en cages flottantes était préférable à l'état de liberte dans des aires plus vastes de substrat naturel. On est ensuite passe a des expériences sur des espèces plus prisees, lorsqu'un petit nombre de specimens juvéniles de turbot sauvage (*Scophthalmus maximus*) sont devenus disponibles, en 1971. Il a fallu modifier les techniques fondamentales d'élevage mises au point sur les plies, notamment pour ce qui concerne la presentation des aliments. Pour obtenir un taux de croissance élevé en cages, on a maintenu les juvéniles de turbot dans une station côtière d'alevinage, tout au long de leur premier hiver, dans de l'eau à basse température, et leur poids a depassé 50 g.

Dans une unité d'alevinage composée de 20 réservoirs de 1 m^3 chacun, continuellement remplis d'eau de mer par pompage, des expériences ont eté réalisées notamment sur des juveniles de turbot d'origine sauvage et, plus récemment, obtenus en écloserie. Des expériences d'alimentation ont ete réalisées en utilisant d'abord une nourriture naturelle composee de crevettes mysidées, on a ensuite employé de la pâte de poisson humide, et enfin des granulés humides composes de farine de poisson maigre, de déchets de filetage, de dérivés de soja et d'un mélange liant vitaminé. Il a fallu réchauffer l'eau ambiante, portant sa température entre 12° et 15°C, pour permettre la croissance et la survie d'un nombre suffisant de spécimens, suivant l'etat du stock à l'arrivee en station d'alevinage.

La plupart des juveniles obtenus en écloserie ont été transferés en station d'alevinage trop jeunes, ce qui a accru la mortalite. On recommande de ne transférer a l'avenir les stocks d'écloserie qu'une fois qu'ils auront atteint au minimum 0.5 g. Les juvéniles d'écloserie n'étaient pas agressifs et le taux de survie et de conversion alimentaire après passage à l'alimentation artificielle était supérieur à celui du stock sauvage.

Preparación de una técnica para la cría en vivero del rodaballo *Scophthalmus maximus* desde la metamorfosis hasta una talla que asegure su desarrollo ulterior—progresos realizados desde 1970 por la British White Fish Authority

Extracto

Desde 1965, la White Fish Authority de Gran Bretaña se ocupa de preparar metodos para el cultivo de peces lenguados marinos. Los primeros ensayos, en los que se utilizaron platijas (*Pleuronectes platessa*), indicaron que el cultivo intensivo en jaulas flotantes es preferible al cultivo extensivo libre en zonas mas amplias, sobre un substrato natural. En 1971, los trabajos experimentales pasaron a ocuparse de especies mas valiosas al disponerse de un pequeno numero de formas juveniles de rodaballo (*Scophthalmus maximus*) criadas en el medio natural. Fue necesario modificar las técnicas básicas de cria preparadas con la platija, especialmente en lo relativo a la presentación de los piensos. Para obtener una elevada tasa de crecimiento en las jaulas, los rodaballos se criaron durante su primera estación invernal en un criadero situado en la orilla, hasta que alcanzaron una talla de más de 50 g.

Se han realizado experimentos en un criadero con 20 tanques de 1 m^3 de volumen, con agua de mar bombeada continuamente, utilizando sobre todo formas juveniles de rodaballo de origen silvestre y, más recientemente, rodaballos procedentes de vivero. En los experimentos de alimentación realizados se utilizó inicialmente una ración natural de camarones misidos, posteriormente se empleó pasta húmeda de pescado y, finalmente, alimentos granulados más complejos a base de harina de pescado blanco, desechos de fileteado, derivados de soja y una mezcla de vitaminas/aglutinantes. Para lograr un crecimiento y supervivencia satisfactorios ha sido necesario elevar la temperatura del agua entre 12 y 15°C, dependiendo de la calidad de los peces al entrar al criadero.

La mayoría de la formas juveniles procedentes de vivero se transfirieron al criadero cuando eran demasiado pequeñas, por lo que la mortalidad fue más elevada. En el futuro se recomienda que los ejemplares procedentes de vivero deben de haber alcanzado una talla mínima de 0,5 g antes de su traslado. Los peces procedentes de incubadora no se comportaron agresivamente y mostraron mejores índices de supervivencia y conversion de alimentos después de ser alimentados artificialmente si se comparan con cepas silvestres.

1 Introduction

Since 1965, when significant numbers of juvenile marine flatfish first became available, the British White Fish Authority has been developing culture methods with the object of introducing commercial farming of such species. Using plaice (*Pleuronectes platessa*) as the experimental animal, following the development of hatching techniques by the Ministry of Agriculture, Fisheries and Food (Shelbourne, 1975) and the Authority, early experiments involved the seeding of large water volumes on a natural substrate with newly metamorphosed fish (Howard, 1974). Results quickly indicated that intensive cultivation in floating cages (Howard and Kingwell, 1975) using young fish which had been acclimatized to high density ongrowing conditions, was preferable.

Experimental work progressed to more highly valued species (Jones, 1972; Kerr, 1974) in 1971, when a small number of juvenile wild stock turbot (*Scophthalmus maximus*) became available. The basic husbandry techniques first used with this group of fish were those developed for

plaice. Early experience indicated that the feed presentation methods established with plaice had to be changed radically. It was also found that in order to obtain a high growth rate in the ongrowing stage, juvenile turbot should not be transferred to floating cages during the winter period of low water temperatures. Furthermore, a significant enhancement in ongrowing performance was achieved when the mean weight of the juveniles on transfer to offshore cages was increased to over 60 g, compared to 30 g, the minimum size consistent with acceptable survival (Hull and Edwards, 1979). The larger fish were able to adapt more readily to ongrowing husbandry conditions but, as shown in this paper, their nursery heating requirements were more expensive.

Despite rapid progress in the sixties in the development of hatchery techniques with plaice and Dover sole (*Solea solea*), it was 1970 before the first turbot larvae were taken through to metamorphosis by the Ministry. Since then, the numbers produced have increased each year, with significant numbers being achieved in 1974.

Since 1971, progress has been made in the development of the nursery technique to produce young turbot, at a mean weight in excess of 50 g at the end of their first winter. This report describes the progress to date, and includes the first experience with the Authority's hatchery-reared stock.

2 Husbandry methods

2.1 *Equipment*

All newly metamorphosed turbot, whether of wild or hatchery origin, intended for ongrowing in floating sea cages, were maintained over their first winter in an onshore nursery. The nursery unit comprised a building (18 × 7 m) in which 20 asbestos tanks, each about 1 m^3 in volume (2 × 2 × 0·3 m approximately), were arranged in a manner to allow good access. Natural daylight was restricted by curtaining the windows in the building; artificial lighting was continuously provided by fluorescent tubes.

Sea water was continuously pumped through the tanks and run to waste. Since 1974, the water has been obtained from a sub-sand filtration system to obviate the problem of weed fouling the pump inlet. The water inflow to the tank, from above the free surface, was directed to cause mild circulation within the tank around the central outflow which, by means of a double standpipe system, drained from the tank bottom. Supplementary oxygen was provided by continuous aeration. Originally, the purposes of the aeration were to cause water mixing and maintain the stock during pump failure but, since innovation of the sub sand filtration system, the aeration has become essential, as the incoming sea water contained 20–30% less oxygen than water pumped directly from the sea.

2.2 *Water quality*

The salinity of the water pumped into the nursery tanks varied between 28 and 35 ppt dependent on weather conditions. The ambient temperature of the water varied seasonally between 6° and 16°C approximately, as illustrated in Fig. 1. A heating plant of 30 kW total capacity was installed to raise the water temperature during winter. The heating system comprised five units to permit individual control of temperature in experimental tanks.

2.3 *Stock*

The majority of stock used was turbot of wild origin, collected in shallow water in North Wales. Due to the natural size divergence of wild stock it was necessary to grade the fish into size groups on capture, to facilitate weaning onto artificial diets without loss through cannibalism.

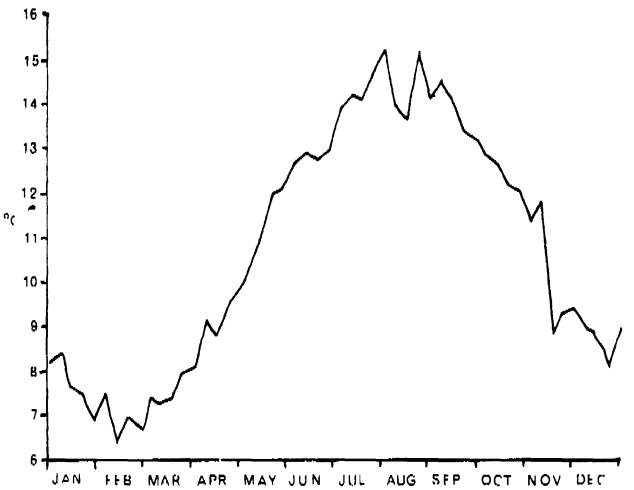


Fig 1. Mean weekly seawater temperatures for a typical year

In 1974, three stocks of turbot produced in the Authority's experimental hatchery were reared in the nursery unit.

2.4 *Stocking and flow rates*

Each tank of 1 m^3 approximate volume, was initially stocked with about 500 juvenile turbot.

Water flow was maintained at or above 0·04 m^3/hour, the minimum so far demonstrated to be sufficient for good feeding activity.

2.5 *Feeding*

The first batch of wild stock turbot held in 1971 did not undergo a true nursery phase, being merely weaned onto an artificial diet in onshore tanks before transfer to offshore cages, as was then current practice with plaice. The ongrowing feeding method was the provision of a trough filled with wet fish paste (Thain and Urch, 1972), with the juveniles being gradually acclimatized to this feeding procedure from their original diet of natural and even live feeds during the period of onshore nursery residence.

Turbot refused, however, to adapt to this feeding procedure. They preferred a slow-sinking, discrete particle of food, refusing to attack a portion which they were unable to accommodate in one mouthful. A partially successful system was devised for presenting the wet paste in the required particulate form, but for the following year group of turbot (1972) a moist composite pellet, WFA 6 (Table I), which fulfilled the physical requirements and gave good growth and conversion efficiency, was developed by the Authority (Thain and Urch, 1973).

TABLE I
COMPOSITION OF MOIST COMPOSITE PELLET, WFA6

Ingredients	%	*Analysis*	%
White fish meal	40	Moisture	41
Reclaimed filleting offal	20	Protein	39
Soybean derivative	5	Ash	12
Vitamin/binder mixture	15	Oil	5
Tap water	20	Carbohydrate	3
Total	100	Total	100

By 1973, the development of the nursery feeding regime was sufficiently advanced for the formulation given in Table I to be adopted as standard in subsequent years. In the standard feeding method, a natural diet in the form of mysid shrimps, *Mysis* sp., was administered to promote an immediate feeding response and restore vigour and health of the young fish after transfer, either from the hatchery or from the site of collection from the wild. The first artificial diet proffered was a wet paste, based on skinned cod roe and finely-minced white fish muscle. Thereafter the wet paste diet was replaced by the pelleted diet, as soon as the turbot reached a size capable of consuming a 2 mm diameter particle.

The mysids were presented by hand in a freshly killed or stunned condition. The cod roe/fish paste was administered through a syringe in 'worm-like' particles, the regularity of feeding being reduced in accordance with weaning response. The pellet diet was presented by hand, with one feed to satiation per day.

Conversion rates quoted in this paper can be defined as follows: (*i*) Wet weight conversion– wet weight of food per unit wet weight of fish produced; (*ii*) Protein efficiency ratio (PER)—wet weight of fish produced per unit weight of protein consumed; (*iii*) Conversion efficiency- the percentage of wet food consumed which is converted into wet fish flesh.

2.6 *Stock handling*

Newly metamorphosed turbot were found to be susceptible to myxobacterial infection if damage resulted from careless handling. For this reason, it was found advantageous to delay initial sampling for length and weight until acclimatization to nursery conditions had been accomplished, after 4–6 weeks.

Stock samples were obtained thereafter by enticing the fish into a feeding response and collecting them by net from midwater with the minimum of stress: this method did, however, tend to select larger, more vigorously feeding individuals.

To minimize damage during stock grading, the process was carried out under water, the original stock being introduced to a partially submerged, mesh container. The mesh size was used to regulate the size grade of fish, as the smaller fish actively moved through to the outer container.

3 Results

3.1 *1971–73*

The results obtained in the nursery are summarized in Table II for the first three year groups of juvenile turbot captured from the wild.

Subsequent poor growth of the 1971 stock in the ongrowing cages was attributed: (*i*) to transference from the nursery at too early a date, when, at the onset of winter, seawater temperatures were below 8°C, and (*ii*) to the fish being too small to withstand the stress.

Therefore, juveniles from the following year group (1972) were held onshore over the entire winter period of low seawater temperature, the nursery tank temperature being maintained between 12° and 14°C (up to 6°C above ambient). After an early 93·5% mortality due to water pumping problems, growth was good using the moist composite pellet (Table I). A mean weight of 65 g was achieved at the end of the nursery period, with a wet weight conversion rate of 1·64:1. Subsequent growth in the floating cages matched that expected in wild populations (Hull and Edwards, 1979).

TABLE II
SUMMARY OF RESULTS— TURBOT OF WILD ORIGIN YEAR GROUPS 1971, 1972 AND 1973

Year Group	*1971*	*1972*	*1973*
Initial Data			
Stocking Date	11/7/71	2/11/72	21/10/73
No. of Fish	1 179	1 422	2 084
Mean Weight (g)	2·5	2·3	2·5
Intermediate (Post Mortality) Data			
Date		25/1/73	26/2/74
No. of Fish	no count made	94	700
Survival %	-	6·5	33·5
Mean Weight (g)	-	7·2	10·0
Final Data			
Date	20/12/71	20/6/73	20/5/74
No. of Fish	1 035	92	698
Mean Weight (g)	3·5	65·0	29·4
Wet Weight Conversion		1 64.1	1 63.1
Temperature Regime (°C)	Ambient	12- 14	10 5 14

In 1973, turbot arrived in the nursery from the capture site infected with *Vibrio anguillarum*. This caused a 66·5% mortality during the first four months of nursery residence. Subsequent growth and food conversion were good and the fish were transferred to ongrowing cages at a mean weight of approximately 30 g. The growth of these fish in the floating cages was disappointing in comparison with that of the previous year-group, the poorer performance being attributed to their smaller size at the time of transfer (Hull and Edwards, 1979).

Since 1973, nursery trials have been directed toward identifying the effects of temperature on growth rate and heating and pumping energy consumption, with the eventual aim of raising juveniles to a size of 50–60 g by early summer (May/June) as economically as possible.

3.2 *Temperature dependence trial—1974 wild stock*

In 1974, a trial was initiated to investigate more thoroughly the value of elevated temperatures, whilst maintaining part of the stock at temperatures previously found acceptable. It was acknowledged at the commencement of the trial that growth of the turbot would be greater at higher temperatures (Purdom, Jones and Lincoln, 1972), but the effect on food conversion and survival was unknown. Six nursery tanks were each stocked with 500 juvenile turbot of wild origin, one tank containing graded large individuals. Water temperature was maintained at: 18°C in two tanks, 14°C in two tanks and seawater ambient in two tanks. After 20 weeks of the 30 week trial, the growth of the fish in the two tanks at 18°C was such that the corresponding increase required in the flow rate caused it to exceed the capacity of the heating unit: the temperature had to be reduced to between 14°C and 16°C until the end of the trial. The results of the trial are summarized in Table III.

All mortalities in the heated tanks were the result of cannibalistic aggression. The mortalities always occurred within the smaller size groups in each population, many of which were culled when observed to exhibit damage (particularly at the anterior and posterior body margins) caused by partial ingestion by larger turbot. No sign of disease was found and on segregation from the larger healthy stock, complete recovery was possible in many instances.

TABLE III
TEMPERATURE DEPENDENCE TRIAL — 10/10/74 8/5/75

Initial stock grade of turbot[1]	Temp regime (°C)	Final mean weight (g)	Survival %	Final stocking density kg/m³	Wet weight conversion	PER	Conversion efficiency %
Large	18/14	70 8	85 4	22 0	2·04:1	1 57	49·0
Small	18/15	51 5	72 4	18 6	2 00:1	1 56	50·1
Small	14	27 5	74 6	10 2	2 17:1	1 40	46·1
Small	14	32 6	70 4	11 5	2 04:1	1·50	49·0
Small[2]	Ambient	4·7	1·6		5·34.1	0·47	18·7
Small[2]	Ambient	4·7	5·6		4·57:1	0·55	21 9

[1] Initial stock grades (mean weight). Large 3 7 g, Small 1 3 g
[2] The data for stocks held at ambient temperatures extend only to 19 March 1975, except for the data on survival, which were measured on 16 April 1975 after which these stocks were discarded

Survival in the ambient tanks was over 80% until March 1975, when high mortality was caused by an outbreak of disease attributed to debilitation through prolonged exposure to low water temperatures (Fig. 1).

Growth of the fish, as illustrated in Fig. 2, was related to the temperature regime in each tank, with the original size of the stock having a significant effect.

The food conversion performance of the fish in heated water was uniform, with no significant difference either between 18° and 14°C or between large and small grade stocks. Using the standard feeding regime (see paragraph 2·5), wet weight food conversion varied between 2·00:1 and 2·17:1.

At ambient temperature, conversion was much poorer, being 5·34:1 and 4·57:1 on a wet-weight basis.

After starting the above temperature dependence trial, there was a residue of 1 700 healthy juvenile turbot which had been collected from the wild in 1974. These were graded as for the temperature trial, one stock of large individuals being separated from two stocks of smaller grade fish. All were maintained in the nursery in ambient conditions until 14 March 1975, by which time one tank of small fish had experienced 100% mortality, and the other tank of small fish was undergoing rapid depletion of numbers due to a disease outbreak, again attributed to low water temperature. The stock of large fish, however, withstood the period of low ambient seawater temperatures with a survival of approximately 90%. This stock responded to a subsequent elevation of water temperature in April 1975 by increasing feeding activity and growth (the mean weight of these fish increased from 7·0 g to 13·9 g in eight weeks).

3.3 *1974—Hatchery stock*

In 1974, the first significant numbers of turbot were produced by the Authority's hatchery for evaluation in the nursery. The husbandry experience gained with turbot of wild origin was applied and modified when indicated by observation. Generally, fish were transferred from the hatchery to the nursery because of pressure for hatchery space rather than because they had attained a suitable size and life-stage. Thus with few exceptions, the stock was transferred prematurely.

Three batches of juvenile turbot from the hatchery were received into the nursery as shown in Table IV.

The first batch to reach metamorphosis was transferred when growth of a filamentous seaweed (*Enteromorpha* sp.), within its hatchery tank caused mortality through occlusion of the fishes' gill cavity. The few fish surviving on 10 October 1974 were mixed with a stock of turbot of wild origin, of similar size, maintained at a temperature of approximately 18°C over the winter period.

TABLE IV
1974 TURBOT OF HATCHERY ORIGIN
COMPARISON OF BATCHES I, II AND III

	Batch I	Batch II	Batch III
Date of transfer	30/7/74	24/9/74	22/10/74
Initial mean weight (g)	0 13	~1·0	~0·5
No. of fish transferred	316	550	880
Weaning survival %	3 5	63·1	50·0
Final mean weight (g) (5/6/75)	103 8	77·0	37·7
Final survival %	3 5	59 1	46·1
Final stocking density kg/m³	*	25·1	15 4
Wet weight conversion	*	1·65 1	1 74:1
PER	*	1 90	1·80
Degree of normal pigmentation %	100	31·7	49·9

* No data available amalgamated with wild stock

The second batch comprised the largest 550 juveniles within the hatchery, selectively transferred to one tank in the nursery unit. Again, seaweed growth caused mortality, and difficulty was experienced in producing sufficient live food in the hatchery.

The third batch was the remainder of the hatchery stocks from which the second transfer batch had been selected. These fish were generally much smaller, with a wide divergence in size; the group also included some unmetamorphosed fish.

In order to maintain the water temperature between 10·5° and 14°C during the winter, as shown to be acceptable to the wild stocks, the second and third batches were supplied with water heated 5–6°C above ambient. From mid-April 1975, the required flow rate dictated by the stock density exceeded the heating capacity and thereafter the temperature was maintained between 10° and 12°C.

Survival during weaning varied between 3 and 63%, whilst survival after weaning was between 92 and 100%, all mortalities being amongst the smallest fish.

Growth of the fish is illustrated in Fig. 3.

No food conversion data are available for Batch I, as the fish were mixed with wild stock. The wet food conversion performance of Batches II and III were very similar, being 1·65:1 and 1·74:1 respectively over the entire nursery period.

The most obvious characteristic of the turbot of hatchery origin was the abundance of abnormally pigmented specimens, rarely encountered in wild metamorphosed turbot stocks. Although all of the eleven survivors from Batch I were completely normally pigmented, only 31·7% and 49·9% of Batches II and III respectively were more than 95% normally pigmented.

The hatchery-reared turbot were observed to be basically more lazy and sluggish than wild stock. Once the

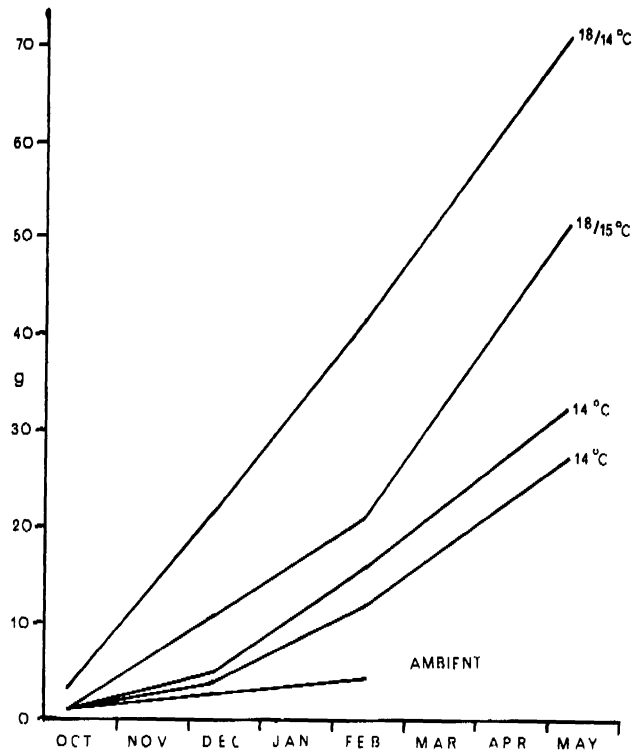


Fig 2. Temperature dependence trial 1974–75 mean weight increase

metamorphosed fish had taken up a bottom dwelling existence, they were rarely seen to move, except in direct response to feeding stimulus or direct physical interference. Moreover, the cannibalistic aggression which was exhibited strongly by the larger wild turbot toward smaller individuals, was never observed.

4 Discussion

4.1 *Survival*

Survival rate over the winter period in the nursery unit was dependent upon the initial size of the fish and the temperature regime of the water in which they were held. Comparison of the results between wild and hatchery stocks cannot be made directly because the latter were transferred prematurely from the hatchery.

Only wild stocks were held in ambient water conditions. Of the five stocks so held, only the largest grade (mean weight 7 g) survived well, with 91% remaining alive in the spring. The smaller grades (range in mean weight 1·3–4·7 g) exhibited at best a 6% survival. As older turbot survive well during their second and subsequent winters in ambient water (Hull and Edwards, 1979), it is inferred that the minimum weight for overwintering at water temperatures below 10°C is not much less than 10 g. In the trials conducted at 12°C and above, the only identified cause of mortality was cannibalism, which is discussed later.

The hatchery-produced fish were transferred to the nursery when hatchery facilities became overloaded and not at the time when the fish were sufficiently large. The first batch were the youngest transferred, weighing on the average only 0·13 g each. Over three quarters of these fish died within 24 hours of transfer, suggesting that the actual movement was the cause of death. Of the few that survived (3·5%) it is considered that they came from amongst the largest fish transferred in this batch: in subsequent comparison they must therefore be regarded as a selected population.

Although the fish in the second and third batches of hatchery juveniles were larger, they still contained too many individuals insufficiently large to accept the weaning diets which had proved almost completely acceptable to the juveniles of wild origin. This showed up in the pattern of mortalities in these batches. As the majority of the deaths occurred amongst the smaller fish between five and ten days after transfer from the hatchery, it was more likely that starvation was the major cause, rather than the stress of the transfer. It appeared that fish of less than about 0·5 g in individual weight were unable to consume the particles of the nursery diet. Although it is thought that, by growing the fish to a minimum of 1·0 g before transfer from the hatchery, the nursery survival could be raised to the nearly 100% level achieved with the wild stocks, it is considered that this policy would create too many problems within the hatchery. Even if fish of 0·5 g, the minimum desirable size, were taken as the size for transfer from the hatchery, it is possible that a survival of 70% could be exceeded. At present this is considered a reasonable target for the 1976 trial programme.

Once the hatchery fish accepted the nursery diet, survival was good, being over 92% for all temperatures tested (12° 18°C).

One further cause of losses was cannibalism; this was observed in the wild stocks, but not in the hatchery stocks which had a more docile nature. The maximum loss due to this cause was 30% over an eight-month period, in an ungraded, vigorously growing stock. As it seems probable that regular grading to reduce the range of sizes held in one tank could virtually eliminate cannibalism, trials are in progress with 1975 0-group wild stocks; if future hatchery stocks do not show this aggression, this problem may be dismissed as a factor in commercial operations.

4.2 *Growth*

It is well established that, within limits, increased temperature results in increased growth rate in marine flatfish, provided nutrition is adequate. This was amply demonstrated by the results of the temperature dependence trial (Fig. 2), where growth rate at 18°C was far superior to that at 14°C and growth at ambient temperatures (6°–10°C) was negligible. Whilst it was undoubtedly easier to handle fish with a larger initial weight, it has yet to be demonstrated that they have a greater growth rate potential. From the graphs in Figs. 3 and 4, it would appear that this is true, but the graphs in Fig. 2 suggest that there is little difference. The variation in survival, with higher mortality amongst the smaller fish, masks the differences. In paragraph 4.1 it was explained that the survivors of hatchery Batch I were large fish upon transfer and therefore comparable to those in Batch II, which were selected on the basis of their larger size. Both batches gave similar growth rates (Fig. 3) displaced only by the time difference in hatching. This, however, infers that a temperature difference of 6°C had no effect upon growth rate, which is patently not true, or that in fact the fish in the second batch had a greater growth potential. The slower growth rate exhibited by the third batch suggests that it had a lower growth potential, which is consistent with it being the residue of the hatchery produced fish once the larger fish, forming Batch II, had been removed.

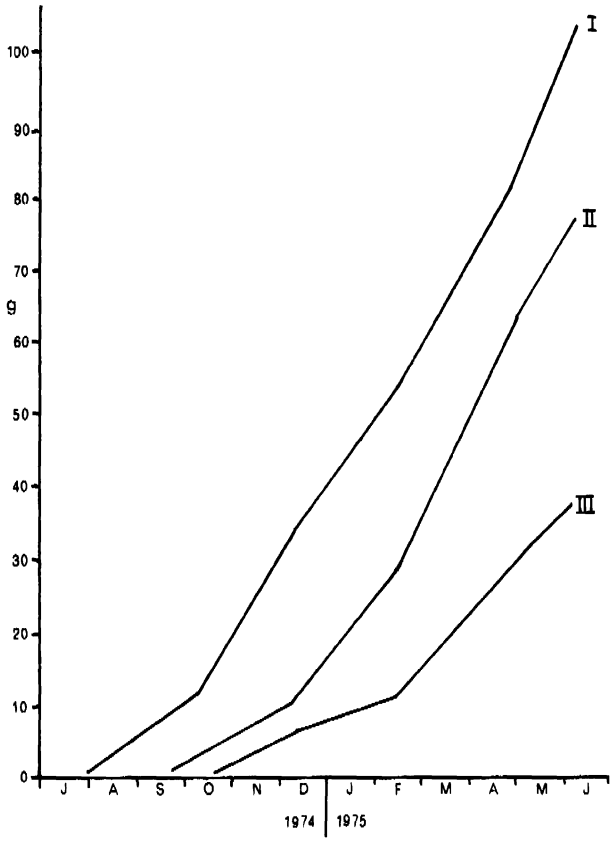


Fig 3. Increase in mean weight of hatchery origin fish Comparison of Batches I, II and III

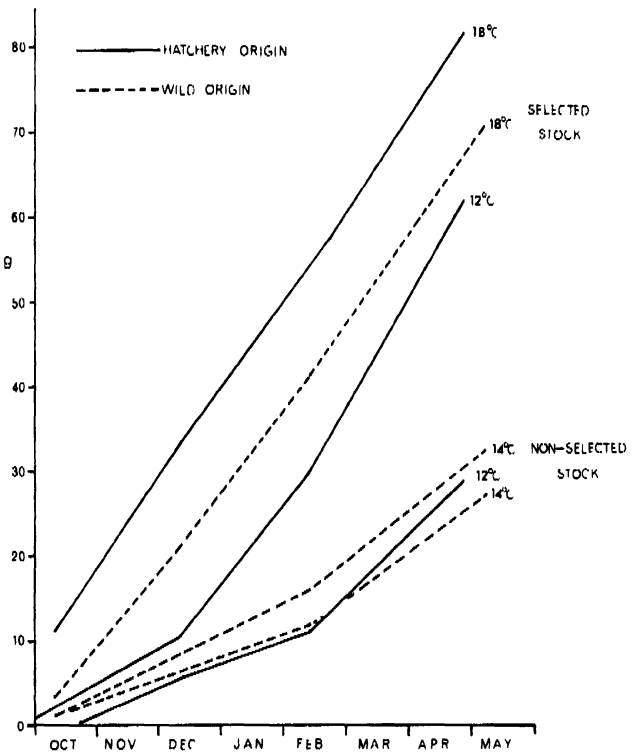


Fig 4. Growth of turbot 1974–75. Comparison of mean weight increase of fish of wild and hatchery origins

Fig. 4 illustrates the growth of the three hatchery batches in comparison with wild stock fish held within the nursery over the same time period. It is immediately apparent that a similarity in growth rate exists between selected stocks of both hatchery and wild origin, and between non-selected stocks of both origins. The actual growth rates of the selected hatchery fish (0·39 g/day and 0·38 g/day) were superior to the selected wild stock (0·33g/day). Similarly, the non-selected hatchery fish had a growth rate of 0·18 g/day compared to 0·13 g/day and 0·15 g/day in wild stock fish. This superiority in growth rate of the hatchery stock is evident despite the apparent enhancement of mean weight increase in the wild stock through the mortality of the smaller fish due to cannibalism.

4.3 *Temperature/duration in nursery phase*

From the results presented it can be seen that, during the nursery stage of turbot rearing, the water must be heated to produce juveniles suitable for ongrowing. In order to take advantage of the summer period of relatively high ambient seawater temperatures for ongrowing in cages, the juveniles must leave the nursery at the beginning of June, by which time they must have achieved a mean weight in excess of 50 g to reach the minimum marketable size of 450 g in two summers of ongrowing (Hull and Edwards, 1979).

Due to the high cost of heating water, it is economically crucial to determine the lowest temperature regime which will enable turbot of 50 g to be produced at an age of approximately one year. However, the situation is complicated by the variation in growth rates of stocks of fish of different initial size and origin. Selected hatchery stock reached mean weights of 103·8 g and 77·0 g in the nursery at temperatures of 18° and 12°C, so it is concluded that a temperature of 12°C is enough to achieve the desired size of fish. Non selected hatchery fish reached 37·7 g at 12°C, but in a period of nursery residence shorter by two months, indicating that this temperature would be sufficient to achieve fish of 50 g weight in a full year. Non-selected wild stock fish reached mean weights of 27·5 g and 32·6 g at 14°C, and 51·5 g at 18/15°C, in a nursery trial completed one month before an age of one year had been attained. From extrapolation of the 14°C growth curves in Fig. 2, this temperature is indicated as being slightly too low for a final mean weight of 50 g to be achieved at an age of one year. Selected wild stock reached a mean weight of 70·8 g at a temperature of 18/14°C, and would thus require less heat than non-selected stock to attain 50 g at the end of the nursery stage. The minimum water temperatures over winter, for the various grades of origin are summarized below:

Stock grade	*Temperature regime (°C) required to produce a mean weight over 50 g at an age of one year*
Selected, hatchery origin	12
Non selected, hatchery origin	12
Selected, wild origin	12- 14
Non-selected, wild origin	15

There has as yet been no experience in transference of stock to ongrowing cages later than early summer. As a later transfer would allow greater flexibility in nursery operations, this option is being investigated in trials which began in 1975.

4.4 *Food conversion*

Food conversion data for fish maintained in heated water over the entire nursery period are available only for the 1974 year-group. The superiority of conversion by fish of hatchery origin (1·65:1–1·74:1) compared to 2·00:1–2·17:1 by fish of wild origin, was attributed to their more docile nature.

5 Conclusions

(*i*) In order to produce turbot stock which will grow vigorously in cages floating in the sea, an onshore nursery phase with heated water is required to provide the juveniles with the correct environment for growth and survival over their first winter period.

(*ii*) To rear juveniles of a mean weight in excess of 50 g at an age of 12 months, by which time they are ready for transfer to ongrowing conditions, it is necessary to maintain the nursery water temperature between 12° and 15°C over winter, depending upon the initial stock grade. Hatchery-produced juveniles grew better in cooler water (12°C) than their wild counterparts.

(*iii*) In vigorously growing stocks of turbot of wild origin, a mortality of up to 30%, attributed to cannibalistic aggression, was experienced in ungraded stock. This aggression was not present in stocks of hatchery origin.

(*iv*) Hatchery reared turbot were better 'farm animals' than domesticated wild stock. Their non-aggressive, more sluggish behaviour led to higher survival (and better food conversion) once weaning onto an artificial diet had been accomplished.

(*v*) To produce nursery survivals better than 70%, further developments are required in the hatchery procedures, to permit the juveniles to be grown to a weight of at least 0·5 g before transfer.

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Observaciones Preliminares en Acuarios Sobre Incubación y Alevinaje de Aterínidos (*Chirostoma* spp.) Del Lago de Pátzcuaro, Michoacan

A. Armijo Ortiz y L. Sasso Yada

Extracto

El trabajo intenta determinar las condiciones físico químicas adecuadas para la obtención de crías de aterínidos y conocer la factibilidad de su cultivo comercial.

Se utilizaron acuarios y garrafones para las experiencias de incubación y alevinaje. Los huevos se obtuvieron mediante las colectas y por fecundación artificial. Se presentan los datos de sobrevivencia de huevos de charal (*Chirostoma bartoni*) en transporte húmedo empleando bastidores y cajas de poliestireno, comparandolos con el transporte en agua. Se determino el tiempo máximo que pueden permanecer los huevos de pescado blanco (*C. estor*) en medio húmedo. Este sistema resultó más eficiente que el transporte en agua.

Se describe el crecimiento utilizando diversos alimentos en'los primeros estadios. Los alimentos proporcionados a las crías son adecuados en los primeros días de vida. Los resultados de crecimiento demostraron que se podría obtener un modelo matemático de crecimiento para *Chirostoma* spp.

Preliminary aquarium observations on incubation and rearing of atherinids (*Chirostoma* spp.) in Lake Patzcuaro, Michoacan

Abstract

The purpose of the work was to determine the best physico-chemical conditions for obtaining atherinid fry and the feasibility of rearing them on a commercial basis.

The incubation and rearing experiments were conducted in aquaria and carboys. The eggs were obtained by collection and artificial fertilization. Data are provided on the survival of charal (*Chirostoma bartoni*) eggs transported in a moist medium in cases and boxes of polystyrene, as compared with shipment in water. The maximum time that white fish *C. estor* eggs can survive in a moist medium was determined. This system proved more efficient than shipment in water.

An account is given of their growth utilizing feeds of different kinds during the first stages. The foods administered to the fry are adequate in the first days of life. Growth results showed that a mathematical growth model could be derived for *Chirostoma* spp.

Observations préliminaires sur l'éclosion et l'alevinage en bassin des atherinidés (*Chirostoma* spp.) dans le lac de Patzcuaro, Michoacan

Resumé

Les travaux susmentionnés avaient pour objectif de specifier les conditions physico-chimiques qui permettent d'obtenir des alevins d'athérinidés et de déterminer la viabilité de leur élevage sur une base commerciale.

On a utilisé des bassins et des bacs pour proceder aux expériences d'éclosion et d'alevinage. Les oeufs ont été obtenus par collecte et par fécondation artificielle. Le document donne les données relatives à la survie des oeufs de *Chirostoma bartoni* transportés en milieu humide dans des caisses en polystyrène, en les comparant avec les résultats obtenus par le transport dans l'eau. L'on a déterminé la période maximale de resistance des oeufs de *C. estor* en milieu humide. Ce procede s'est révelé plus efficace que le transport dans l'eau.

La croissance est decrite en fonction du temps, avec l'indication des divers aliments administres aux premiers stades du developpement.

Les aliments fournis aux alevins se sont revelés adequats durant les premiers jours de leur vie. Les résultats obtenus en matière de croissance ont demontre que l'on pourrait mettre au point un modèle mathématique de la croissance pour les athérinides.

1 Introducción

Las especies de Aterinidos de las aguas dulces de México correspondientes al género *Chirostoma*, se conocen comúnmente con los nombres de charal y pescado blanco (Fig. 1 y 2). Los charales, de los que existen alrededor de 20 especies presentes en numerosos rios, lagos, y presas, son de tamaño pequeño y regularmente miden de 8 a 12 cm.

El pescado blanco (*Chirostoma estor*) es el de mayor talla que se captura en México y puede llegar a medir algo más de 30 cm; sin embargo, su distribución no es tan

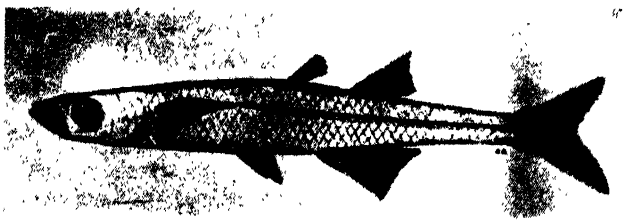


Fig 1. Chirostoma bartoni. Charal



Fig 2 Chirostoma estor Pescado blanco

amplia como la del charal. Las áreas de captura de esta especie son principalmente el Lago de Chapala, Jal. y el Lago de Pátzcuaro, Mich. Son peces de hábitos carnívoros y las crías, después de haber consumido el saco vitelino, se alimentan de protozoarios y rotíferos. Cuando miden unos 5.5 mm se alimentan a base de microcrustáceos (Rosas, 1970). Los juveniles y adultos de pescado blanco se alimentan de crustáceos mayores y peces (Solórzano, 1963). Tanto el pescado blanco como el charal se reproducen en el Lago de Pátzcuaro durante todo el año, pero la época de reproducción del charal se acentúa entre enero y mayo y la del pescado blanco entre enero y agosto (Solórzano, 1963).

Los aterínidos mexicanos y en especial el pescado tante sean especies de importancia económica. Los trabajos existentes se refieren a aspectos biológicos y taxonómicos del género *Chirostoma* o bien a aspectos limnológicos del lago de Pátzcuaro. De Buen (1944) trabajó en el período comprendido entre 1939 y 1944 como asesor de la Estación Limnológica de Pátzcuaro, sobre aspectos limnológicos e ictiológicos del lago, haciendo observaciones también sobre el mantenimiento de charales (*C. bartoni* y *C. grandocule*) en estanques y acuarios. Solórzano (1961 y 1963) estudió el aspecto biológico de dos aterínidos del Lago de Pátzcuaro. Rosas (1970) es el primero que trabajó sobre cultivo de *C. estor* del Lago de Pátzcuaro, especialmente sobre el manejo, alimentación, transporte y comportamiento de las crías de pescado blanco.

2 Objetivos

Los objetivos de este trabajo fueron: determinar las condiciones físico químicas adecuadas para la obtención de crías de aterínidos a partir de la incubación artificial de los huevos y contribuir al conocimiento de la factibilidad del cultivo comercial de estas especies y en especial de *C. estor* a través de las experiencias sobre mantenimiento, alimentación, crecimiento, transporte y comportamiento.

3 Desarrollo del trabajo

El trabajo se desarrolló en el laboratorio del Programa de Piscicultura Experimental del Instituto Nacional de Pesca. Para las experiencias de incubación y alevinaje se utilizaron acuarios de 98 × 38 × 38 cm con una capacidad de 141.5 l y de 49 × 24 × 30 cm y capacidad de 35 l. Se emplearon también garrafones de plástico y de vidrio invertidos de 30 cm de diámetro y 26 cm de altura con 17.2 l de capacidad. Los experimentos se llevaron a cabo en dos épocas del año (invierno y primavera) por lo cual se pudo experimentar con un amplio rango de temperaturas del agua. También se llevó a cabo el experimento en peceras con temperatura del agua constante.

La oxigenación del agua se mantuvo mediante un compresor de aire empleando manguera fina de plástico. Durante la incubación se utilizaron piedras porosas para facilitar burbujeo suave. A fin de disminuir la turbulencia del agua se hicieron, para la producción de alevines, pequeñas perforaciones en la manguera. Se experimentó con peceras bajo la luz y en obscuridad. En este último caso se cubrieron las paredes con papel y colocó encima de la pecera un vidrio cubierto también con papel.

Los huevos de charal se obtuvieron mediante colecta en las áreas de desove mientras que los huevos de pescado blando se obtuvieron de ejemplares maduros capturados y fecundados artificialmente. El conteo de los huevos se hizo con el método gravimétrico restando al final el peso húmedo de los colectores. La determinación del tiempo máximo que pueden permanecer los huevos en condiciones de humedad se determinó introduciendo una cantidad determinada de ellos en el agua cada 24 horas, observando su desarrollo y anotando la mortalidad hasta la eclosión.

3.1 *Colecta y transporte de huevos*

Los huevos de charal se encontraron adheridos a las raíces del lirio acuático en las áreas de desove (Fig. 3 y 4).



Fig 3. Huevos de *Chirostoma* sp. en raíces de lirio acuático

Para los huevos de pescado blanco se utilizaron como substrato de fijación raíces de lirio acuático y colectores artificiales de fibras plásticas. Para el transporte se emplearon bastidores de madera de 35 × 29 cm envolviendo los huevos por debajo y por encima con una tela suave de algodón, humedecida para evitar la deshidratación. Los 5 bastidores se colocaron en una caja de poliestireno de 40 × 40 × 25 cm para mantener la temperatura constante (Fig. 5 y 6).

El número de huevos en cada bastidor fue de 3 000 lo que equivale a 15 000 en cada caja. El tiempo utilizado para el transporte desde el área de colecta hasta el laboratorio fue de 7 horas aproximadamente, manteniéndose durante este trayecto una temperatura constante en el interior



Fig 4. Area de desove

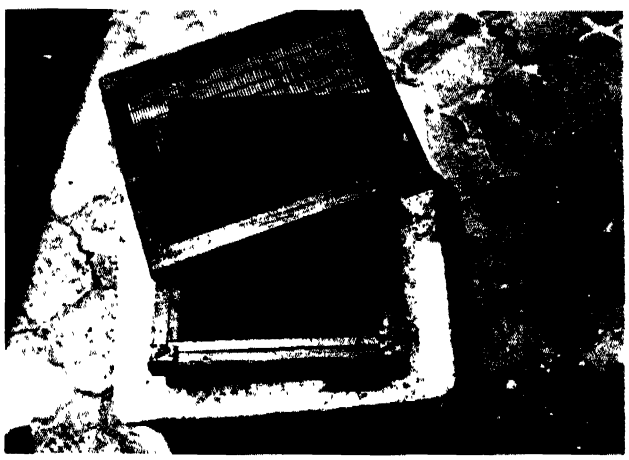


Fig 5 Caja y bastidores para transporte

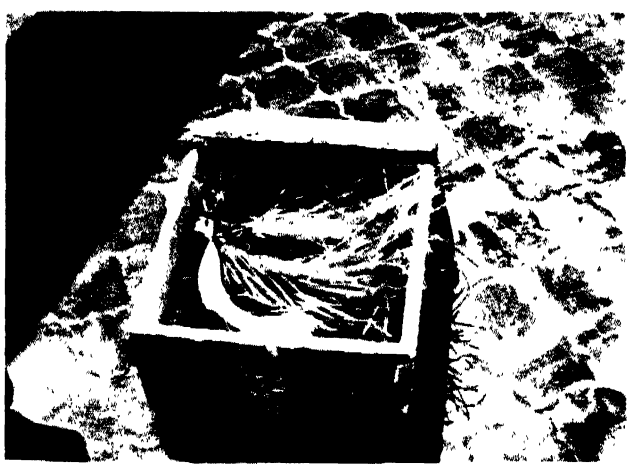


Fig 6. Colectores artificiales

de las cajas, de 21°C en invierno y 23°C en verano.

3.2 *Incubación*

Al llegar al laboratorio los huevos se colocaron en las peceras; 3 000 en cada acuario pequeño y 10 000 en cada acuario grande. Los colectores fueron puestos indistintamente en el fondo o en la superficie del agua. En el caso de los huevos de pescado blanco se agregó una solución de azul de metileno al 1% para prevenir la invasión de hongos.

Durante el tiempo que duró la incubación no se hizo ningún cambio de agua, por la falta de agua declorinizada en cantidades suficientes. En las peceras mantenidas a temperatura ambiente, la mínima temperatura registrada fue de 17.5°C y máxima de 22°C promedio y en aquellas con calentador la temperatura varió entre 26.5 y 27°C.

3.3 *Alevinaje*

El número de crías nacidas se determinó por diferencia con el número de huevos encontrados muertos adheridos a los colectores. La mortalidad de las crías se determinó por conteo directo. Se experimentaron 5 tipos de alimentos: yema cruda disuelta en agua; yema cocida suministrada a través de una malla fina; levadura disuelta en agua; cultivos de protozoarios y agua fertilizada con materia orgánica.

4 Resultados

Con los bastidores y la tela humedecida fueron transportados 15 000 huevos por caja. Este medio de transporte permitió obtener del 95% al 98% de supervivencia desde la colecta hasta su introducción en las peceras. Se comprobó también que los huevos de pescado blanco pueden permanecer en las cajas hasta 144 h en el medio húmedo, desde su fecundación hasta su introducción en el agua con una mortalidad del 2%. Aún cuando los huevos se encuentran en diferentes estados de desarrollo, el transporte utilizado no los afecta. La eclosión de estos no es uniforme, pues se encuentran en diferentes etapas de desarrollo, por lo que la eclosión se lleva a cabo en un tiempo máximo de 4 días a una temperatura promedio del agua de 21.5°C y con un pH promedio de 7.4. Los huevos de *C. estor*, obtenidos por fecundación artificial, eclosionaron a los 8 o 9 días a temperaturas del agua de 21 a 22°C con un pH promedio de 7.2. Las crías recién nacidas consumieron el saco vitelino en un lapso de 5 a 8 días. En los tres días subsiguientes se alimentaron con levadura y después con la yema de huevo cocida; la yema cruda se precipitó rápidamente sin ser consumida por las crías. Los protozoarios cultivados fueron bien aceptados pero acidificaron el medio (descendiendo el pH en 7 décimas) en un lapso de 4 días. Lo mismo sucedió con el agua fertilizada. La supervivencia de las crías alimentadas con levadura y yema cocida fue en promedio del 55% (120 días). A partir de entonces se alimentaron con 'pulgas de agua' (*Daphnia* sp.) vivas coladas, aumentando paulatinamente la mortalidad hasta el 95% (250–270 días). Los datos sobre el crecimiento se expresan a continuación y en Fig. 7 y 8.

Edad en días	*Talla promedio (mm)*	*Talla mínima (mm)*	*Talla máxima (mm)*
—			
30	14		
60	18	12	25
90	21	14	29
120	36	31	40
150	49	43	58
180			
210	86	84	89

Los peces mantenidos en la obscuridad y bajo las

mismas condiciones de alimentación que aquéllos mantenidos bajo la luz, crecieron de manera similar.

Condiciones	*Edad en días*	*Talla promedio (mm)*	*Talla mínima (mm)*	*Talla máxima (mm)*
Luz	90	21	14	29
Obscuridad	90	18	12	29

Las crías de charal con saco vitelino pueden mantenerse en bolsas de polietileno con agua, infladas con oxígeno durante 5 h sin movimiento con una mortalidad del 40%. Las crías sin saco vitelino pueden permanecer en las mismas condiciones durante 5 h con una mortalidad del 10%.

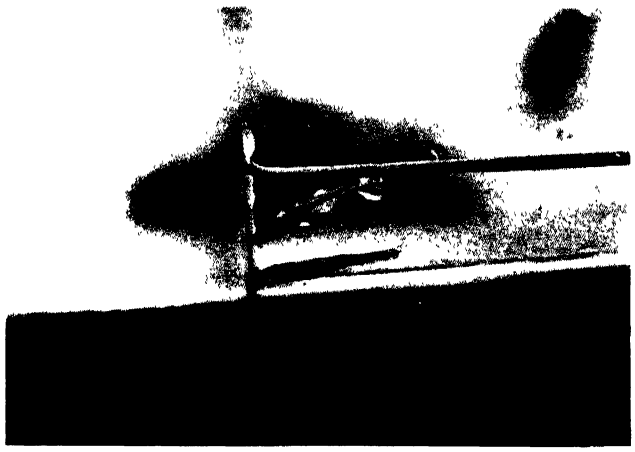


Fig. 7. Chirostoma sp 2 meses de edad

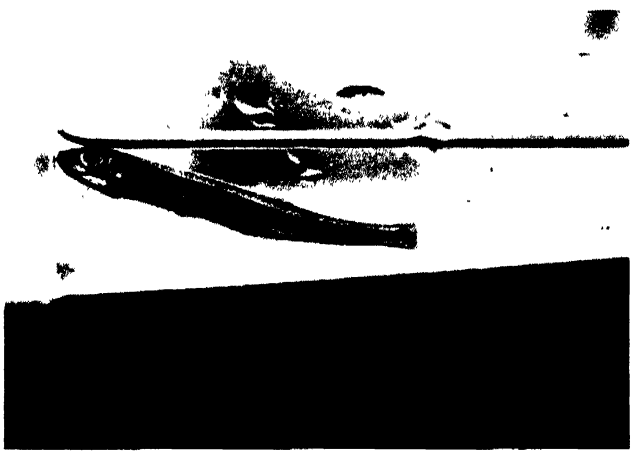


Fig. 8 Chirostoma sp. 5 meses de edad

5 Discusión

Los bastidores usados para asegurar la buena oxigenación de los huevos, pueden ser suprimidos y aumentar el número de huevos en unas diez veces. El transporte en medios húmedos nos permite aumentar el número de huevos transportados. El método realizado hasta la fecha en grandes volúmenes de agua, además de aumentar el peso grandemente, dificulta el transporte.

Como se menciona en los resultados, se dejaron los huevos hasta 144 h en la cámara húmeda y aún así la mortalidad fue mínima de sólo 2%. Los huevos de charal se han colectado en diferentes estadios de desarrollo. Esto nos hizo pensar que por el avanzado desarrollo (huevos oculados) aumentaría la mortalidad. Sin embargo, los resultados nos han demostrado que no importa el estadio en que se encuentren los huevos, la mortalidad es siempre la misma entre 2% y 5%.

Rosas (1970) menciona que el pescado blanco nace a temperaturas de 20°C en 168 h y a temperaturas de 23°C en 120 h, mientras que nosotros obtuvimos los nacidos después de más de 192 h a temperaturas de 21 y 22°C. Este hecho ocurrió quizás porque en este caso la temperatura descendió mucho debido a una falla en el transporte. Rosas (1970) obtuvo en estanques a los 45 días crías de 11 mm y a los 90 días de 30 mm. Durante nuestros experimentos se obtuvieron a los 30 días crías de charal de 14 mm, a los 90 días de 21 mm y a los 7 meses de 86 mm.

Los alimentos experimentados con las crías que han consumido el saco vitelino, que aportaron mejores resultados, fueron levadura durante los tres primeros días y luego yema de huevo cocida. Se pudo observar que los protozoarios cultivados son bien aceptados pero el agua se hace ácida rápidamente. Es posible que controlando el pH oportunamente y variando o mezclando levaduras y protozoarios al principio y luego yema de huevo cocida se pudieran obtener mejores resultados y mejor aún haciendo uso del cultivo de rotíferos para alimentar las crías mayores.

El número de crías que sobrevivieron (5%) lograron un crecimiento muy adecuado, como se puede observar en la Fig. 9. En los 3 primeros meses el crecimiento fue lento, pero en los meses siguientes la talla aumentó rápidamente, como lo demuestra la curva. Haciendo un esquema gráfico en papel semilogarítmico se obtiene una recta, lo que nos demuestra que la curva es exponencial.

Las experiencias con crías en bolsas se hicieron con el objeto de conocer el tiempo que pueden permanecer así, pero los datos que obtuvimos pueden variar si estas bolsas son transportadas. Según se cree el movimiento contínuo del agua mata mayor número de peces.

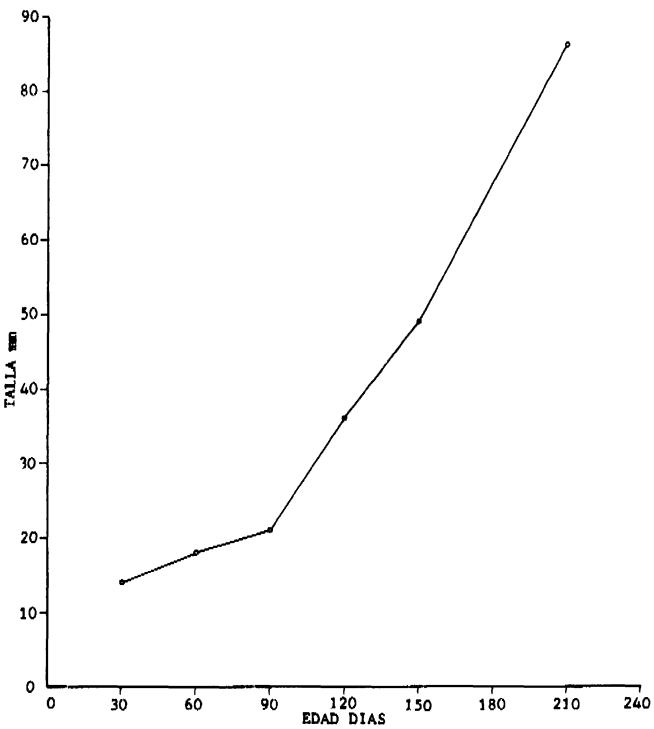


Fig 9. Crecimiento de *Chirostoma* sp. en acuarios (talla promedio)

6 Conclusiones

Se considera que el transporte de los huevos en un medio húmedo es mucho más eficiente que el transporte en agua.

Los huevos colocados en cámara húmeda sobreviven un tiempo muy prolongado sin notarse problemas aparentes en el embrión. Los alimentos suministrados como levadura, yema de huevo cocido y protozoarios cultivados son adecuados para estos peces en los primeros días de vida, pero habría que probar mezclas de ellos y experimentar con otros alimentos para etapas subsiguientes. Como se puede observar en la gráfica, los resultados obtenidos son muy adecuados para una curva exponencial de crecimiento. Esto nos hace pensar en la posibilidad de poder preparar un modelo matemático de crecimiento para *Chirostoma* sp.

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Intensive Culture of Indian Major Carps

R. D. Chakrabarty, P. R. Sen, N. G. S. Rao and S. R. Ghosh

Abstract

An experiment on intensive polyculture of the Indian major carps catla (*Catla catla*), rohu (*Labeo rohita*) and mrigal (*Cirrhinus mrigala*) was undertaken in freshwater ponds in India in 1974–75 to determine better methods of increasing production of these prized food fishes of great commercial value.

These major carps were stocked in two previously cleared ponds, one, 0.19 ha, the other 0.17 ha using 6 000 fingerlings per ha in a species ratio of catla 3: rohu 4: mrigal 3. Management measures involved fertilization with cow dung, urea, triple superphosphate, and ammonium sulphate, and supply of artificial feed, a mixture of ground nut oil cake and de-oiled rice polish in equal proportions by weight.

The ponds were harvested after a year; gross productions recorded for the two were 3 930 and 3 017 kg/ha/yr, the best average growth of around 800 g being obtained in catla. It was possible to determine the sex of the majority of the harvested fish by external examination. Females on an average weighed more than the males, this being especially marked in mrigal which attain sexual maturity earlier than the other two.

Gross productions between 3 000–4 000 kg/ha/yr as were obtained in this experiment are indicative of the high yields that can be obtained by intensive polyculture of these Indian major carps in freshwater ponds in India. A stocking density of 5 000 fingerlings/ha in the ratio of catla 4: rohu 3: mrigal 3 might result in fish of greater average weight within a year and as such prove more attractive commercially.

Culture intensive de carpes indiennes

Résumé

En 1974/75 on a entrepris une experience de polyculture intensive des carpes indiennes catla (*Catla catla*), rohu (*Labeo rohita*) et mrigal (*Cirrhinus mrigala*) dans des étangs d'eau douce de l'Inde, pour determiner quelles sont les meilleures méthodes pour accroitre la production de ces poissons comestibles de grande valeur commerciale.

On a empoissonné avec ces carpes indiennes deux etangs auparavant vides, l'un de 0.19 ha, l'autre de 0.17 ha, en y déposant 6 000 alevins par hectare selon le rapport spécifique suivant: catla 3: rohu 4: mrigal 3. Les mesures d'amenagement ont comporté la fertilisation des étangs au moyen de bouse de vache, d'urée, de superphosphate triple et de sulfate d'ammonium, et l'approvisionnement en aliment artificiel — un mélange de tourteaux d'arachide et de riz poli déshuilé en proportions egales par poids.

La récolte a été faite au bout d'un an; les chiffres de production brute enregistrés pour les deux etangs ont été de 3 930 et de 3 017 kg/ha par an, le meilleur taux de croissance moyen (environ 800 g) ayant été obtenu avec la carpe catla. Il a été possible de déterminer le sexe de la majorité des poissons récoltés par examen externe. En moyenne, les femelles pesaient plus que les mâles, cette différence étant particulièrement accusée chez le mrigal qui atteint la maturité sexuelle plus tôt que les deux autres espèces.

La production brute de 3 000 à 4 000 kg/ha/an atteinte lors de ces expériences indique que l'on peut obtenir des taux de rendement élevés par la polyculture intensive de ces carpes dans les étangs d'eau douce de l'Inde. Une densité d'empoissonnement de 5 000 alevins/ha dans les proportions de catla 4: rohu 3: mrigal 3 pourrait donner en un an des poissons d'un poids moyen plus élevé; comme telle, elle se revele plus attrayante du point de vue commercial.

Cultivo intensivo de las principales carpas indias

Extracto

En 1974/75 se realizó en la India un experimento de policultivo intensivo de las principales carpas indias - catla (*Catla catla*), rohu (*Labeo rohita*) y mrigal (*Cirrhinus mrigala*)— en estanques de agua dulce, para determinar mejores metodos para aumentar la producción de esos peces, de gran valor comercial para la alimentación.

Se sembraron esas especies en dos estanques limpiados previamente, uno de 0.19 ha y otro de 0.17 ha, a razón de 6 000 jaramugos por ha, en la siguiente proporción: catla 3: rohu 4: mrigal 3. Durante la explotación se fertilizaron los estanques con estiércol de vaca, urea, superfosfatos triples y sulfato amónico, y se facilitaron a los peces piensos artificiales: una mezcla de torta oleaginosa de cacahuete y salvado de arroz del que se había extraído previamente el aceite, en iguales proporciones en peso.

La producción bruta de los estanques al cabo de un año fue de 3 930 y 3 017 kg/ha por año: el mejor crecimiento medio, de unos 800 g, se obtuvo con catla. Fue posible determinar el sexo de la mayoría de los peces extraídos mediante examen externo. Las hembras, en promedio resultaron más pesadas que los machos sobre todo las carpas mrigal, que alcanzan la madurez sexual antes que las otras dos.

La producción bruta entre 3 000–4 000 kg/ha por año obtenida en este experimento indica los elevados rendimientos que pueden obtenerse del policultivo intensivo de estas carpas indias en estanques de agua dulce. Una densidad de siembra de 5 000 jaramugos/ha en proporción catla 4, rohu 3, mrigal 3 permitiría obtener al cabo de un año peces de mayor peso medio y, por tanto, haría más atractiva comercialmente esta actividad.

1 Introduction

The rearing of major Indian carps, catla (*Catla catla*) a surface feeder, rohu (*Labeo rohita*) a column feeder and mrigal (*Cirrhinus mrigala*) a bottom feeder is the commonest type of pond fish culture practised in India. Hora and Pillay (1962) considered these cyprinids to be the most important pond fishes of the country. The eastern states of India, particularly West Bengal, have traditions of polyculture of these food fishes chosen for their excellent culture values: rapid growth, attainment of large size, compatibility, keeping quality of the flesh, consumer preference and a hardiness that makes it easy to handle and transport their seed. The availability of their seed and suitable water areas for their culture have also played a role in the development of their traditional culture in eastern India. Indigenous to the Indian sub continent and Burma, these 'Gangetic carps' have also been transplanted to peninsular India, where they have established themselves in most of the major rivers (Alikunhi, Chaudhuri and Ramachandran, 1952), and to countries such as Israel, Malaysia, Mauritius, the Philippines and Sri Lanka.

2 Traditional fish culture in India

Fish culture as practised in India is generally of the homestead type, and there is not much marketable surplus. Commercial fish culture relying mostly on empirical

methods is, nevertheless, practised in West Bengal and to some extent, in adjoining states. In such traditional fish culture, primary reliance is placed on the inherent fertility of the ponds; and without the application of measures such as fertilization and feeding, the production as might be expected—is rather low. The average production, for example, may be only about 600 kg/ha/year as observed by Banerjea (1967) for a number of ponds. In special situations (Saha and Mazumdar, 1970) increased fish production of indigenous carps may be obtained through utilization of city sewage as is practised in some areas around Calcutta.

3 Scientific fish culture in India

Culture of indigenous major carps stocked in desirable proportions in ponds cleared of predators and pests, and fertilized to increase production of natural fish food, and with artificial feeding has now been developed through scientific research, and its increasing application has provided higher yields. In experimental studies undertaken by the Central Inland Fisheries Research Institute, at Cuttack and elsewhere, varying productions of the indigenous carps have been obtained. Parameswaran *et al* (1971) obtained productions ranging from 843 to about 2 000 kg/ha/yr. Gross productions of 2 535 and 2 193 kg/ha/yr were obtained at Cuttack (Jhingran, 1974). The higher productions were associated with the use of fertilizers and feed. Chaudhuri *et al* (1975) recorded high productions of 2 596–3 137 kg/ha/yr of the Indian major carps stocked in association with the exotic carps, common carp (*Cyprinus carpio*), silver carp (*Hypophthalmichthys molitrix*) and grass carp (*Ctenopharyngodon idella*) and using fertilizers and feeds. Chakrabarty *et al* (in press) observed increased fish production through use of fertilizers and feed along with fertilizers. Such studies indicated the desirability of using fertilizers and feeds to obtain a higher production from indigenous carps, and formed the basis for the experiment reported upon below.

4 The present experiment

The experiment was undertaken in two adjacent ponds of the Killa Fish Farm of the Central Inland Fisheries Research Institute at Cuttack in 1974–1975. The ponds were weed-free and rain-fed and had previously been cleared of fish using a pesticide, mahua oilcake (*Madhuka latifolia*). Their proximity minimized the chances of variation in pond environment; it was considered that they were replicates.

A so-called 'composite' fish culture of Indian major carp species together with the Chinese silver carp, grass carp and common carp has produced high yields of marketable fish averaging over 8 000 kg/ha/yr (Chaudhuri *et al*, 1975). This was undoubtedly due to fuller utilization of the pond's ecological niches by the species and numbers of fish introduced. Such mixed cultures, however, are not possible when seed of the grass and silver carps—production of which in India is wholly dependent upon hypophysation—are not available. The lesser response to hypophysation of these exotic species in comparison with the indigenous carps, also restricts their culture (Chakrabarty, 1975). Therefore, rapid development of fish culture over wide areas in India now requires use of the indigenous carps, whose seed is more readily available.

The objective of the experiment therefore, was to determine whether high yields could be obtained through intensive culture of the indigenous species alone in small ponds of a type common in India.

4.1 *Stocking densities and species ratios*

The two freshwater ponds, Pond A with an area of 0·19 ha and Pond B of 0·17 ha, were stocked with catla, rohu and mrigal in the ratio of catla 3: rohu 4: mrigal 3 by number. The stocking density was 6 000 fish per ha. The fish ranged from 102 to 262 mm in length and from 32·5 to 159 g in average weight. The fingerlings used had been reared from seed obtained by hypophysation. The stocking density and the species ratios selected were based on results obtained by earlier workers.

4.2 *Management techniques*

The techniques adopted for raising the carp were similar to those evolved for polyculture at the Cuttack Substation (Chaudhuri and Chakrabarty, 1975), except that no weeds were provided. Both fertilizers and feeds were selected on the basis of their effectiveness in previous experiments.

The kinds of fertilizers and their amounts used in the ponds are shown below. They were added in instalments. Cowdung was added each month in small heaps at the pond margins, to allow for gradual dissolution.

Fertilizer	kg/ha/year	
	Pond A (0·19 ha)	Pond B (0·17 ha)
Cowdung	6 117	6 838
Urea	53	59
Ammonium sulphate	53	59
Triple superphosphate	131	147
Commercial lime	105	121

The supplementary feed used was a mixture 1:1 by weight of groundnut oil cake (about 40% protein) and good quality de-oiled rice polish (about 10–12% protein). The utility of groundnut oil cake as a feed for major carp fry has been reported by Chakrabarty *et al* (1973). The oil cake and rice polish, both in flake form, were broadcast in particular corners of the ponds at fixed hours each day. Feeding was stopped altogether on a few days when blooms of the dinoflagellate *Peridinium* sp appeared. The total quantities of feed provided for ponds A and B were 8 926 kg/ha/yr and 9 976 kg/ha/yr respectively. Conversion of the feed to fish flesh was 2·3:1 in Pond A and 3·3:1 in Pond B. The best conversion obtained in ponds where silver, grass and common carps were cultured with indigenous carps (by Chaudhuri *et al*, 1975) was 1·6:1, where in addition to fertilizers and supplemental feed, weeds were provided for the grass carp.

4.3 *Soil, water and plankton*

Table I shows the physico-chemical conditions of the pond soil and water.

The texture of the soil in both ponds was sandy loam as shown below.

	Percent	
	Pond A	Pond B
Sand	60	66
Silt	10	10
Clay	28	23

Pond A appeared somewhat more fertile than Pond B,

which to some extent might have contributed to the higher production obtained in the former (see section 4.4 below). The high values for total alkalinity are indicative of productive pond conditions. Banerjea (1967) found ponds with water above 90 ppm total alkalinity to be productive. The available phosphorus values are also satisfactory. The low available nitrogen values of the pond soil and the low organic carbon values do not reflect productive conditions while the sandy loam texture of the soil suggests the possible loss of nutrients added to it. All things considered, the soil appeared to be on the unproductive side. The somewhat better values of the nutrients in the water phase is due to the effect of additions of fertilizers and feed in the course of culture.

The plankton density in Pond A averaged 0·64 cm^3/45 l of strained pond water, and that of Pond B 0·12 cm^3/45 l. Among phytoplankters, *Microcystis, Navicula, Scenedesmus* and *Pediastrum* dominated in Pond A, and *Navicula, Closterium* and *Pediastrum* in Pond B. Prominent among zooplankters were nauplii of copepods, *Moina*, rotifers and *Cyclops*. The higher plankton density reflects the better nutrient status of Pond A.

4.4 *Harvest, survival and growth*

Pond B was harvested a year after stocking. Pond A was harvested five days later, in May. Mahua oil cake was used to ensure the complete removal of fish.

Table II illustrates the results obtained. The total production recorded in Pond A was 3 930 kg/ha/year (3501 kg net) and in Pond B it was 3 017 kg/ha/yr (2 607 kg net). In both ponds the performance of catla was best in survival as well as growth.

During the year, none of the three species was able to obtain an average weight as high as 1 kg as observed in previous polyculture experiments. Table III is a comparison of results with respect to stocking density and survival in Pond A (0·19 ha) (where the best results of the present experiment were obtained) with the results obtained by Chaudhuri *et al* (1975) when the same three species attained average weights of 1 kg in the course of a year, in association with exotic carps.

The difference in growth results may be due to the effect of population density, but consideration should also be given to the beneficial interactions among the species in an association of carps, particularly the contribution of

TABLE I
SOIL CONDITION AND WATER QUALITY OF THE EXPERIMENTAL PONDS

	Soil condition[1]			
	Pond A		*Pond B*	
	Range	*Average*	*Range*	*Average*
pH	6 8 7·3	6 9	6·8–7 3	6 9
Organic carbon (%)	0·10–0 38	0·21	0 12 0 21	0·17
Available nitrogen (mg/100 g)	8·00–16·00	12 46	8·00–14 00	8·98
Available P_2O_5 (mg/100 g)	4·00–16 00	13·10	2 00 10 00	6·30

	Water quality[2]			
	Pond A		*Pond B*	
	Range	*Average*	*Range*	*Average*
Temperature (°C)	24·0–31 8	28 1	24·5 32 2	27·8
Dissolved oxygen (ppm)	4·90–6 00	5 49	4·00 6·25	5·22
pH	7·4 8 8	7·8	7 0 8·4	7·3
Total alkalinity ($CaCO_3$) (ppm)	200·0–260·0	216 6	140·0 208 8	174·0
Dissolved inorganic N (ppm)	0 39 1·30	0·87	0 60 1·35	0 87
Dissolved inorganic P_2O_5 (ppm)	0·30–2 00	0·63	0 20 1·75	0·46

[1] Based on 7 observations over 365 days
[2] Based on 13 observations over 365 days

TABLE II
FISH PRODUCTION IN TWO EXPERIMENTAL PONDS

	Pond A (0 19 ha)			*Pond B (0 17 ha)*		
	Catla	*Rohu*	*Mrigal*	*Catla*	*Rohu*	*Mrigal*
Number stocked	343	459	343	307	411	307
Number recovered	332	380	340	291	232	218
Survival (%)	96·9	82·8	99 1	94 8	56 4	71
Initial average weight (g)	159	35·0	32·5	145 9	33·5	36 2
Final average weight (g)	791 6	723 3	610·9	842 2	641·3	544 2
Production per pond (kg)	262 8	274 9	209·5	245 1	149·1	118 6
	All species			All species		
Gross production (kg/ha/yr)	3 930			3 017		
Net production (kg/ha/yr)	3 501			2 607		

semi-digested and undigested vegetable material by the grass carp as well as the possible benefit derived from droppings of the algae feeding silver carp, and the release of nutrients effected through the digging action of the common carp (Yashouv and Halevy, 1972).

The loss in numbers of rohu and mrigal in Pond B affecting production is attributable mainly to their mortality during blooms of *Peridinium*.

4.5 *Differential growth of the sexes*

Table IV shows the average weights of females and males of the three species examined.

To examine the correctness of sexual segregation of the fish in their early stages of maturity made on the basis of examination of pectoral fin roughness (Chaudhuri, 1959), the fish were dissected and the observations confirmed. Chaudhuri *et al* (1975) recorded better growth of females in mrigal than males. The lower average weight of catla females in Pond A, a contradiction in an otherwise uniform pattern of heavier females in all cases, may be explained by the fact that these fish were in the early stages of maturity.

The greater profitability of culture of more females both for the table as well as for breeding fish is suggested. Major carp roe is also highly relished by fish consumers.

4.6 *Economics of intensive culture of Indian major carps*

An analysis of the profitability of a fish culture operation based upon the results obtained in the experiment in Pond A is presented in Table V.

Items 5, 6 and 7 in Table V are based on estimations since the work was carried out in departmental experimental ponds where these items of expenditure were either not incurred or were difficult to apportion for individual ponds. The sale price of Rs 5·50/kg considered is a modest rate; in the open market the price of such whole fish is much more, around Rs 10/kg. The inputs, except fingerlings, were derived from the open market where prices of these fluctuate.

The economics appear more favourable compared with those reported for Indian major carps by Pillay (1973) for a study made in West Bengal, India. The ratios of profit to operating cost and gross income which he reported were 28·8 and 22·3 as against the higher values of 54·3 and 35·1 in the present experiment vindicating the economic soundness of intensive culture of indigenous carps.

5 Discussion

The intensive culture of Indian major carps alone, employing as high a stocking density as 6 000 fingerlings/ha, may

TABLE III
COMPARATIVE GROWTH AND SURVIVAL OF INDIAN MAJOR CARPS UNDER DIFFERENT STOCKING DENSITIES IN TWO DIFFERENT EXPERIMENTS

	Number stocked (per ha)		*Percentage survival*		*Average weight (g)*	
	Pond A	[1]	*Pond A*	[1]	*Pond A*	[1]
Catla	1 805	780	96·88	88 10	791·6	1 078 0
Rohu	2 415	1 875	82·78	95 08	723·3	994 8
Mrigal	1 805	750	99 12	99·67	610 9	1 129 0

[1] Composite culture experiments of Chaudhuri *et al* (1975)

TABLE IV
DIFFERENTIAL GROWTH OF THE SEXES OF INDIAN MAJOR CARPS

	Pond A (0 19 ha)		*Pond B (0 17 ha)*	
	Average weight (g)		*Average weight (g)*	
	Male	*Female*	*Male*	*Female*
Catla	968 (35)[a]	912 (40)	832 (74)	1 002 (72)
Rohu	730 (25)	870 (73)	635 (54)	643 (59)
Mrigal	400 (48)	650 (58)	558 (29)	659 (37)

[a] Figures in parentheses indicate the number of fish examined

TABLE V
ECONOMICS OF INTENSIVE FISH CULTURE OPERATIONS IN A ONE HA POND BASED UPON RESULTS IN POND A

	Operating cost/ha/year	*Rs*[1]
1.	Stocking material	600
2.	Piscicide	600
3.	Fertilizer (organic manure, chemical fertilisers and lime)	300
4.	Feed	8 110
5.	Labour (including watch and ward, farm labour, pond preparation and harvesting)	3 200
6.	Miscellaneous (transport, depreciation of farm implements, repairs, *etc*)	1 000
7.	Rental	200
		14 010
	Income from sale of 3 930 kg of fish at I.Rs. 5·50/kg	21 615
	Profit,	7 605
	—ratio to operating cost 54 3%	
	—ratio to gross income 35 1%	

[1] Exchange value US $1·00 = Indian Rs 9·00

not yield as high a fish crop as that obtained by culture of these species together with exotic carps. Productions recorded by Chaudhuri *et al* (1975) employing a lower stocking density of 5 000 fingerlings/ha were higher than those obtained in our experiment. Nevertheless, production touching 4 000 kg/ha/year as obtained in Pond A, indicates that production of the indigenous major carps alone could be increased by intensive management.

The comparatively better performance of catla in a culture system relying mainly on supply of artificial feed is worth noting. A production of about 1 400 kg/ha alone of catla as obtained in Pond A in contrast to 901 kg/ha/year, the highest obtained for the species in composite fish culture experiments by Chaudhuri *et al* (1975) is worth mentioning. In a mono-culture experiment with catla (Alikunhi and Sukumaran, 1964), the production obtained was 1 193 kg/ha/year. The benefit derived by catla from artificial feed may be less than that for rohu and mrigal but the presence of proteolytic enzymes in the species, as mentioned by Ranade and Kewalramani (1967), suggests physiological capability of utilizing a high protein diet like groundnut oil cake. The utilization of groundnut oil cake in feed by catla fry was observed by Chakrabarty *et al* (1973).

The production of about 1 500 kg/ha/year of rohu from Pond A is worth comparing with the record production of 2 640 kg/ha/year of rohu obtained in intensive polyculture by Chaudhuri *et al* (1974), if in both instances the performance of the other indigenous species of carps are also taken into account. The combined production of the Indian major carps alone in this case was slightly over 4 250 kg/ha/year compared to 3 930 kg/ha/year in Pond A. The former pond received more inputs including fingerlings of exotic carps.

The nutrient status of the pond soil in the present experiments indicates that the ponds had rather low productivity, not uncommon among existing Indian fish ponds.

6 Conclusions

The practicability of employing intensive polyculture of the highly desirable major carps of India, the catla, rohu and mrigal, to raise sizeable fish crops from freshwater ponds, is demonstrated by the experiments reported upon here.

The average sizes obtained indicate that under the management measures used, the stocking density/ha/yr was a little on the high side for attainment of desired marketable weight of 1 kg. Perhaps a density of 5 000 fingerlings/ha with catla, rohu and mrigal stocked in the ratio of 4:3:3 would give fish of larger average weight which would be more attractive commercially.

In areas where grass, silver and common carp seed is available, culture of these species in association with indigenous carps is to be advocated for high fish production. But, when exotic carp seed is not available, water areas can be gainfully utilized through intensive culture of Indian major carps alone. Productions of around 3 000 kg/ha/year appear possible.

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Some Experiments on Intensive Farming of Common Carp in Poland

J. Szumiec

Abstract

Intensive pond farming of common carp (*Cyprinus carpio*) is a promising and effective method of fish production with many advantages over the older system in which the carp were dependent upon natural foods for their entire nutrition. The bases for this intensive farming are: (*i*) use of stabilized complete feeds, (*ii*) high stock density; and (*iii*) improved techniques in farming.

During long-term research at the Experimental Fish Culture Station of the Polish Academy of Sciences at Gołysz, three important problems concerned with intensive carp farming were solved: (*i*) determination of methods for using complete artificial feeds; (*ii*) determination of the effectiveness of feeds differing in nutritional values and stability; and (*iii*) setting economic and biological limits for the complex intensification of pond production.

Experiments were started in 1969 in 1 500m² ponds, using 2 400 K_{2+} carp per hectare, with the aim of obtaining fish of 1 000g weight. (As controls, ponds neither fertilized nor provided with feed were stocked with 300 carp/ha.) Feeding began at the end of April and lasted to the end of September. Rations were provided (using self feeders) as a proportion of body weight calculated every fortnight, and were varied with water temperature. They were also varied somewhat depending upon the appetite of the fish and the water's oxygen content. The ponds were fertilized with lime, ammonium nitrate and superphosphate at intervals.

Three feeds were tested, (*i*) pellets of 25% protein, mostly of plant origin; (*ii*) doughy food of the same composition, (*iii*) wheat. The best water stability was shown by the pellets followed by the wheat and then the dough. Growth of fish feed with pellets was higher by 606 kg/ha than fish fed with dough (despite the same protein content), but growth for pellet fed fish was only 139 kg/ha better than wheat – an insignificant

difference. Fish fed with pellets yielded 3 347 kg/ha, those with wheat 3 199 and those with dough 2 727.

Experiments repeated in 1970 with a higher stocking density (3 000 K_{2-3}/ha), showed no significant difference between feeding with pellets or wheat.

Experiments in 1971 had an even higher stocking density (3 600 K_{2-3}/ha) and a 'super pellet' containing 40% protein mostly of animal origin was used. The best results were obtained with super pellets, followed by standard pellets and then wheat.

In 1972 and 1973 even higher stocking densities were used. With a stocking (in 1972) of 4 000 K_{2-3}/ha and feeding with super pellets, the yield was 4 909 kg/ha. At 10 000 K_{1-2}/ha, the yield in kg/ha was 4 647 with super pellets, 4 199 with standard pellets and 3 182 with wheat. In 1973, experimental ponds stocked at 4 000 K_{2-3}/ha and with feeding of super pellets, yielded 4 954 kg/ha. A normal farm pond of 2 ha also stocked with 4 000 K_{2-3}/ha and with super-pellet feeding yielded 5 412 kg/ha.

The yield (1969–73) in control ponds, unfertilized and without feeding, stocked at 300 K_{2-3}/ha varied from 180 to 241 kg/ha. The yield in ponds fertilized but without feeding (1971–73) stocked at 900 K_{2-3}/ha varied from 477 to 518 kg/ha.

In all the experiments (1969–73) survival was high: 93–100%.

The results show that ponds in good condition can provide 2 000–3 000 kg/ha with carbohydrate foods and 3 000–6 000 kg/ha with protein-rich pellets. The use of feed can also be reduced to about 2 kg of feed to 1 kg of carp.

The chief obstacle to further intensification of carp production is the deterioration of the pond environment with increased fertility. Nevertheless, further intensification is possible by stabilizing the dissolved oxygen content at 4–6 mg/l by pond aeration.

Quelques experiences d'elevage intensif de la carpe commune en Pologne

Résumé

L'élevage intensif en étang de la carpe commune (*Cyprinus carpio*) est une méthode de production de poisson efficace et riche en possibilités, qui presente de nombreux avantages sur l'ancien systeme selon lequel les carpes dépendaient d'aliments naturels pour toute leur nutrition. Les bases de la pisciculture intensive sont les suivantes: (*i*) utilisation d'aliments complets stabilisés; (*ii*) forte densité du stock; et (*iii*) techniques perfectionnées d'élevage.

Lors de recherches à long terme menées à la Station de pisciculture expérimentale de l'Académie des sciences de Gołysz, l'on a résolu trois problèmes importants en matière d'élevage intensif des carpes: (*i*) détermination des méthodes d'utilisation des aliments complets artificiels; (*ii*) détermination de l'efficacité d'aliments de valeur nutritionnelle et de stabilité différentes; (*iii*) définition de limites économiques et biologiques pour l'intensification globale de la production en étang.

Des experiences ont commencé en 1969 dans des étangs de 1 500 m², avec 2 400 K_{2-3} carpes par hectare, dans le but d'obtenir des poissons d'un poids de 1 000 g. (On a empoissonné des étangs temoins que n'étaient ni fertilisés ni enrichis par des aliments au taux de 300 carpes par hectare.) L'alimentation a commencé fin avril et s'est prolongée jusqu'à fin septembre. Les rations administrees par distributeur automatique étaient calculées tous les quinze jours en proportion du poids corporel et en fonction de la température de l'eau. Ces rations variaient également quelque peu selon l'appétit des poissons et la teneur de l'eau en oxygène. Les étangs étaient fertilisés périodiquement au moyen de chaux, de nitrate d'ammonium et de superphosphate.

Trois aliments ont été essayes: (*i*) des granulés contenant 25% de protéines, essentiellement d'origine vegetale; (*ii*) un aliment pâteux de la même composition; (*iii*) du blé. La meilleure stabilité dans l'eau a été obtenue par les granulés, suivie par le ble, puis par la pâte. La croissance des poissons nourris de granulés a excédé de 606 kg/ha celle des poissons nourris de pâte (pour une même teneur protéique), mais la croissance des poissons alimentes avec des granulés n'a été supérieure que de 139 kg/ha à celle des poissons nourris de blé—un écart insignifiant. Les rendements ont été respectivement de 3 347 kg/ha pour les poissons nourris de granulés, de 3 199 kg/ha pour ceux nourris de blé et de 2 727 kg/ha pour ceux nourris de pâte.

Les expériences ont été renouvelées en 1970 avec une densité de peuplement plus forte (3 000 K_{2-3} par ha), sans que l'on obtienne des écarts notables entre l'alimentation sous forme de granulés ou de blé.

En 1971 on a fait de nouvelles expériences avec une densité de peuplement encore plus forte (3 600 K_{2-3}) en utilisant des 'super-granulés' contenant 40% de protéines essentiellement d'origine animale. Les meilleurs résultats ont été obtenus par les super-granulés suivies par les granulés standards puis par le blé.

En 1972 et en 1973, on a utilisé des densités de peuplement encore plus élevées. Avec un peuplement (1972) de 4 000 K_{2-3}/ha et une alimentation constituée de super-granulés, le rendement a atteint 4 909 kg/ha. Avec un peuplement de 10 000 K_{1-2}/ha, le rendement a atteint 4 647 kg/ha pour les carpes nourries de super-granulés, 4 199 kg/ha pour celles nourries de granulés standards et 3 182 kg/ha pour celles nourries de blé. En 1973, des étangs expérimentaux contenant un peuplement de 4 000 K_{2-3}/ha alimenté par des super-granulés ont donné une rendement de 4 954 kg/ha. Un étang d'élevage normal de 2 ha contenant aussi un peuplement de 4 000 K_{2-3}/ha alimenté par des super-granulés a donné un rendement de 5 412 kg/ha.

Dans des étangs témoins, sans fertilisation ni alimentation, où le peuplement était de 300 K_{2-3}/ha, le rendement a varié de 180 à 241 kg/ha. Le rendement d'étangs fertilisés mais sans alimentation (1971–1973) et empoissonnés au taux de 900 K_{2-3} s'est situé entre 477 et 518 kg/ha.

Dans toutes les expériences (1969–1973) le taux de survie a été élevé: 93 à 100%.

Les résultats montrent que, dans de bonnes conditions, des étangs peuvent donner de 2 000 à 3 000 kg/ha avec des aliments à base d'hydrate de carbone et de 3 000 à 6 000 kg/ha avec des granulés riches en protéines. Les rations peuvent également être réduites à quelque 2 kg d'aliment pour 1 kg de carpe.

Le principal obstacle à une nouvelle intensification de la production des carpes est la détérioration de l'environnement des étangs qui accompagne un accroissement de la fertilité. Néanmoins, l'on peut réaliser de nouveaux progrès en stabilisant la teneur en oxygène dissous à 4–6 mg/l par aération de l'étang.

Experimentos de cria intensiva de carpa común en Polonia

Extracto

La cría intensiva de carpa común (*Cyprinus carpio*) en estanques constituye un método prometedor y eficaz para la producción de peces, con numerosas ventajas respecto al sistema antiguo, en el que la carpa dependía para su nutrición de los alimentos naturales. Los elementos básicos de la cría intensiva son: (*i*) empleo de piensos completos estabilizados; (*ii*) elevada densidad de repolacion; (*iii*) mejores técnicas de cría.

Durante las investigaciones a largo plazo realizadas en la Estación Experimental de Piscicultura que la Academia Polaca de Ciencias tiene en Gołysz, se resolvieron tres problemas importantes relacionados con la cría intensiva de carpas: (*i*) determinación de los métodos para el empleo de piensos artificiales completos; (*ii*) determinación de la eficacia de piensos de distinto valor nutricional y estabilidad; (*iii*) determinación de los límites económicos y biológicos para la intensificación compleja de la producción en estanques.

Los experimentos comenzaron en 1969 en 1 500 m² de estanques, utilizando 2 400 carpas K_{2-3} por hectarea, para obtener peces de 1 000 g de peso. (Como testigos se utilizaron estanques en los que se sembraron 300 carpas por hectárea, sin fertilizacion ni piensos.) La alimentación con piensos comenzó a finales de abril y duró hasta finales de septiembre. Las raciones se distribuyeron mediante autoalimentadores, en proporción del peso corporal, calculado cada quince días, y se modificaron según la temperatura del agua. Se modificaron también según el apetito de los peces y el contenido en oxigeno del agua. Los estanques se fertilizaron a intervalos con cal, nitrato amónico y superfosfatos.

Se ensayaron tres tipos de piensos: (*i*) gránulos con un 25% de proteínas, principalmente de origen vegetal; (*ii*) un producto pastoso de la misma composicion; (*iii*) trigo. Los mas estables en el agua resultaron los gránulos, seguidos por el trigo y finalmente el producto pastoso. El crecimiento de los peces alimentados con granulos resultó mayor en 606 kg/ha que el de los peces alimentados con el pienso pastoso (a pesar de que el contenido de proteínas era idéntico), mientras respecto a los peces alimentados con trigo la diferencia fue sólo de 139 kg/ha, que es insignificante. Los peces alimentados con gránulos produjeron 3 347 kg/ha, los alimentados con trigo 3 199 y los alimentados con el producto pastoso 2 727.

Los experimentos repetidos en 1970 con una mayor densidad de poblacion (3 000 K_{2-3} por ha) no mostraron diferencias importantes entre la alimentación con gránulos o trigo.

En los experimentos de 1971 se utilizó una densidad de repoblacion aún mayor (3 600 K_{2-3} por ha) y un pienso granulado super, con un 40% de proteínas, principalmente de origen animal. Los mejores resultados se obtuvieron con los gránulos super, seguidos de los gránulos normales y el trigo.

En 1972 y 1973 se utilizaron densidades de repoblación aún mayores. Con una densidad (en 1972) de 4 000 K_{2-3}/ha y alimentando a los peces con gránulos super, el rendimiento fue de 4 909 kg/ha. A 10 000 K_{1-2}/ha, el rendimiento en kg/ha fue de 4 647 con gránulos super, 4 199 con gránulos ordinarios y 3 182 con trigo. En 1973, algunos estanques experimentales sembrados a razón de 4 000 K_{2-3}, alimentados con gránulos super, dieron un rendimiento de 4 954 kg/ha. Un estanque piscícola normal de 2 ha sembrado también a razón de 4 000 K_{2-3}/ha y con alimentación de gránulos super produjo 5 412 kg/ha.

El rendimiento (1969–1973) en los estanques testigo, sin fertilizar y sin piensos, sembrados a razón de 300 K_{2-3}/ha varió entre 180 y 241 kg/ha. El rendimiento en estanques fertilizados pero sin distribución de piensos (1971–1973), repoblados a razón de 900 K_{2-3}, osciló entre 477 y 518 kg/ha.

En todos los experimentos (1969–1973) la supervivencia fue elevada: 93–100%.

Los resultados muestran que utilizando estanques en buenas condiciones pueden obtenerse 2 000–3 000 kg/ha con alimentos a base de carbohidratos y 3 000–6 000 kg/ha con gránulos ricos en proteínas. El uso de piensos puede reducirse a unos 2 kg de piensos por un kg de carpa.

El principal obstáculo para intensificar ulteriormente la producción de

carpas es el deterioramiento del ambiente al aumentar la fertilidad. De todas formas, es posible una mayor intensificación estabilizando el contenido de oxígeno disuelto en 4–6 mg/l mediante un sistema de aireación del estanque.

1 Introduction

Conventional carp culture is based on the use of natural pond foods and not of complete artificial feeds. These natural foods can be used properly only when there is the right proportion in the diet to furnish the aminoacids and vitamins needed by the fish. Thus to attain a high fish production in ponds they must be made very fertile so as to provide an abundance of natural food. However, increase in the natural productivity of the pond causes disturbances in the life conditions of the fish, which limit the possibilities of intensification.

Conventional carp farming requires a large area, much water, and large investments in building as well as upkeep of the pond system and its facilities, this leading to rising costs of production. A serious drawback to this old system is the considerable amount of food necessary for a unit of fish growth. There is reason, therefore, to substitute more intensive forms of carp farming if they prove practicable.

2 The bases of intensive carp farming

The bases for intensive carp farming in ponds are: (*i*) use of stabilized and complete feeds, (*ii*) high density of stock, and (*iii*) improved techniques in farming.

Of these, the most important factor is the use of complete feeds which meet the nutritional requirements of the fish. These feeds must be easy to assimilate, possess high nutrient value, and have high stability in water (Lobaěva, 1959); this is mostly gained by pelleting. To a certain degree, an intensive fattening of carp, especially three-year-olds, is also possible by periodical use of carbohydrate feeds.

The use of expensive complete-food pellets is economical only with high stock density, above the so-called critical point at which the natural pond resources are insufficient to overcome the deficiencies of conventional feeding (Hepher and Cherwinski, 1965). Under the farming and climatic conditions at Gołysz in Poland, this occurs with a stock of approximately 2 500 K_2 or 5 000 K_1 per ha.[1]

The role of natural food in intensive farming is rather small; its share is below 10%, and, when artificially fed, fish do not waste energy in looking for natural food which is not readily accessible.

In calculating the density of stock for intensively cultured ponds, natural pond productivitiy is not taken into consideration, but stock density must be adjusted to the potential possibilities of the pond ecosystem to maintain its biological balance. The fish stock must be afforded the proper living conditions, above all a dissolved oxygen content above 3–4 mg/l. In the present state of farming technique, the optimum stock density in well-designed and well-constructed ponds is 4 000–5 000 K_2 or 7 000–8 000 K_1 per ha.

The density of stock is a factor which has a very complex character. At more than tenfold density, the trophic behaviour of the fish begins to change, and an increased influence of the fish population on the pond environment can be noted. Increased intensification of production is followed by eutrophication of the ponds but the great density of the fish population entirely changes the ecological interdependence in the biotopes of the ponds. This interdependence is not limited, as was once generally believed, only to a reduction of natural food and deterioration of living conditions for the fish. It also stimulates energy flow through the ecosystem, and the dynamics of turnover as well as the productivity of trophic links. Thanks to this the conditions of life in ponds with high stock density are not harmed. Thus high stock density ensures not only economic production but a favourable course of farming.

The third basic factor supporting intensive fish farming is a complex of farming measures that includes fish feeding techniques, pond cultivation and fertilization, improvement of environmental conditions, and protection against disease. Concentration of production on a relatively small area facilitates the application of farming measures and allows a much greater manipulation of environmental processes than is possible with conventional fish farming. It is more economical and technically easier. At the same time, however, the high level of production demands high standards, punctuality in all work, top quality fish stocks, feeds and water, and well-constructed, well-manned ponds.

It has been ascertained that common carp fed on pellets change their trophic behaviour. Pellets are taken three times quicker than is the same amount of wheat. To eliminate long periods during which the carp may lack food it is necessary to introduce automatic or self-feeders. This will also reduce the losses of ingredients from feed which remain for some time in the water. Leaching of feed also leads to a decrease in the effectiveness of feeding owing to reduction in the water's oxygen content.

3 Experiments on intensive carp farming

During the first stage of long-term research work on common carp (*Cyprinus carpio*) at the Experimental Fish Culture Station of the Polish Academy of Sciences at Gołysz it was possible to solve the most important problems. These were: (*i*) determination of methods for using complete feeds, (*ii*) determining the effectiveness of using feeds of various nutritional value and different stabilities, and (*iii*) setting economic and biological limits for complex intensification of pond production.

It was possible to undertake these experiments because in previous years we had mastered the technology of producing carp feed, taking into account its nutritional qualities, its action in water, and the trophic behaviour of carp (Vinogradov and Erożyna, 1962). Complete compounded foods are agglomerated and stabilized by a wet pelleting method (Polunina, 1962). Through application of the technology and equipment of the macaroni industry and using binding elements, a product of high water stability has been obtained. Another advantage of the wet pelleting method is the possibility of using cheap protein-rich by-products of the food industry, either fresh or preserved. This is because the components used in the wet pelleting method are first made into a dough containing about 35% water (Szumiec, 1969).

The feeding experiments at the station were carried out in 1 500 m^2 experimental ponds. During the experiments, mostly two-year carp stock (*Cyprinus carpio*) was used with the aim of obtaining a growth of 1 000 g for each fish.

[1] K_1 indicates carp of one summer season's growth, K_2 of two seasons' growth *etc.*

All the groups of experiments were repeated four times. Self-feeding pendulum feeders were used which enabled the fish to take food at demand.

Feeding started at the end of April and continued to the end of September. Daily rations were provided according to the existing biomass of the fish population which was calculated every fortnight on the basis of test catches. Water temperature was also taken into account. Within each temperature range the following food rations specified as percentages of body weight were accepted as maximum: 15–18°C—2%; 18–21°C—3%; 21–24°C—4%; and over 24°C—5%. Feed rations also varied to a certain degree according to the appetite of the fish, or to the actual current weight of the fish if it differed from the one previously estimated.

The food ration also depended on the oxygen content of the water. In the case of an ascertained or anticipated decrease, the ration was reduced or feeding was even stopped.

Oxygen balance in intensively farmed ponds at the present technical level is based principally on oxygen produced by phytoplankton. Fertilization was used to promote this process. Agricultural lime was spread on the pond bottom, at a rate of 2 000 kg/ha as well as 400–500 kg/ha of ammonium nitrate and 300–400 kg/ha of superphosphate. The ponds were fertilized seven to ten times from April to July at intervals dependent on the intensity of phytoplankton development.

During the farming season the flow of water through the ponds was not constant; only losses from evaporation and soaking were made up.

The experiments had a wide scientific basis. Periodic growth of the carp, the chemical composition and calorific value of their flesh, and the state of their blood and health were observed. Care was taken to note the physical and chemical qualities of the water which have an influence upon feeding. The quality of the pellets was assessed according to their chemical composition, calorific value and stability (Hepher, 1969; Szumiec and Stánny, 1975). Analyses of bacterio-, phyto-, and zoo-plankton and bottom fauna were also made.

In 1969, the ponds were stocked with 2 400 K_{2-3} carp per ha. For comparison, a group of ponds neither fertilized nor provided with feeds, was stocked with 300 carp per ha.

Three kinds of feeds were introduced: (*i*) pellets containing 25% protein, (*ii*) dough of the same composition, and (*iii*) wheat, used as a comparable carbohydrate feed.

The experiments show that the stability of feed is of outstanding importance (Table I). Pellets with the proper composition and high water stability proved to be the best. The carbohydrate feed in the natural form of grain, which has great water stability, proved to be next best. Feed in the form of dough proved to be the least effective because of its tendency to dissolve in water (Szumiec, 1971).

The difference in effectiveness between pellets and dough is considerable, the latter being less effective by 606 kg/ha on the average. The insignificant difference between the results achieved from feeding wheat or pellets (on the average 139 kg/ha) and the large quantity of pellets required for a unit of growth indicated inadequate quality of the pellets.

The lack of distinct differences in results between the complete and carbohydrate feeding further indicated that the stock density used was not high enough to reach the critical point over which the natural supply of pond food becomes insufficient with carbohydrate feeding to furnish the protein and vitamins required by the fish.

The experiments were repeated in 1970 with a higher stocking density, *ie*, with 3 000 K_{2-3} per ha. There was still no noticeable difference between feeding on pellets or wheat.

In 1971, experiments were begun on a larger scale. To achieve more varied effects of feeding, the stock density was increased and feeds with more varied nutritional values were introduced. The standard pellets contain 25% protein, mostly of plant origin, while the new 'super pellets' contain 40% protein, mostly of animal origin. These experiments were carried out in five combinations, these being successive degrees of intensity of production (Table I).

The best results were obtained in one of the ponds where the fish were fed on super pellets. The yield here was 5 033 kg/ha and the growth 3 739 kg/ha, which is 21 times more

TABLE I

MEAN PRODUCTION RESULTS ACHIEVED DURING EXPERIMENTS ON INTENSIVE FARMING OF TABLE CARP

Year	*Group of ponds*	*Stock per ha*	*Growth in kg/ha*	*Yield in kg/ha*	*Average individual weight/growth of fish in g*	*Relative food coefficient*	*Survival rate %*
1969	Control ponds	300 K_{2-3}	191	274	871/ 594	—	100
	Ponds with fish fed on wheat	2 400 K_{2-3}	2 513	3 199	1 369/1 089	3·5	95
	Ponds with fish fed on dough	2 400 K_{2-3}	2 046	2 727	1 347/ 919	4·3	93
	Ponds with fish fed on pellets	2 400 K_{2-3}	2 652	3 347	1 433/1 150	3·8	95
1971	Control ponds	300 K_{2-3}	180	291	1 004/ 632	—	97
	Ponds fertilized, without feeding	900 K_{2-3}	477	792	945/ 596	—	93
	Ponds with fish fed on wheat	3 600 K_{2-3}	2 565	3 845	1 092/ 737	4·2	97
	Ponds with fish fed on standard pellets	3 600 K_{2-3}	2 748	4 018	1 146/ 794	4·1	97
	Ponds with fish fed on super pellets	3 600 K_{2-3}	3 502	4 761	1 371/1 023	3·1	96
1972	Control ponds	300 K_{2-3}	241	324	1 084/ 805	—	99
	Ponds fertilized, without feeding	900 K_{2-3}	518	774	879/ 600	—	98
	Ponds with fish fed on super pellets	4 000 K_{2-3}	3 825	4 909	1 227/ 948	2·2	100
	Ponds with fish fed on wheat	10 000 K_{1-2}	2 321	3 182	327/ 242	3·5	97
	Ponds with fish fed on standard pellets	10 000 K_{1-2}	3 346	4 199	430/ 345	2·7	98
	Ponds with fish fed on super pellets	10 000 K_{1-2}	3 762	4 647	477/ 392	2·2	98
1973	Control ponds	300 K_{2-3}	186	263	929/ 671	—	94
	Ponds fertilized, without feeding	900 K_{2-3}	509	729	845/ 602	—	94
	Ponds with fish fed on super pellets	4 000 K_{2-3}	3 970	4 954	1 231/1 027	2·2	97
	Farming pond (2 ha)	4 000 K_{2-3}	4 434	5 412	1 396/1 152	2·1	97

compared with the natural growth (Szumiec, 1972).

In 1972 and 1973, with a higher stocking density of 4 000 K_{2-3}/ha or 10 000 K_{1-2}/ha even better results were obtained (Table I). In 1973, intensive carp production methods were also applied in a normal farming pond with an area of 2 ha (Szumiec, 1974).

It must be stressed that no great differences were noticeable within separate groups of ponds, and it is also important to notice that in all experiments the survival of fish was very high—from 93 to 100%.

The results achieved have also shown that ponds in a good hydrotechnical state provide the possibility of producing 2 000–3 000 kg/ha when carbohydrate foods are used and 3 000–6 000 kg/ha when protein-rich pellets are used.

The production results achieved here (Table I) fully confirmed the general conclusions drawn from our earlier experiments that intensive table carp farming in ponds ensures a production of 5 000–6 000 kg/ha of a top quality product, and reduces the use of feed to about 2 kg for one unit of growth. Intensive carp farming makes it possible to produce fish more effectively and economically than conventional fish farming does.

Deterioration of the fish's natural environment which occurs with the increase in production and fertility of the pond is to be regarded as the chief obstacle hindering further intensification of pond production. Nevertheless further intensification of carp production in ponds is possible if the concentration of oxygen in the water can be stabilized on a level from 4 to 6 mg/l by pond aeration (Lukowicz, 1974 and 1975; Sauberlich and Bauer, 1975). This increased oxygen level will meet the demand of the fish stock and create the proper conditions for improved biochemical and biological processes in the pond environment.

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The Culture of Common Carp in Japan

R. Suzuki

Abstract

The common carp (*Cyprinus carpio*) has been cultivated for at least 2 400 years in China and 1 900 years in Japan. Its intensive culture has long been practised in Nagano, Gunma and Yamagata Prefectures because they are far from the sea and hence have a poor supply of marine fish, and once had an abundant supply of silkworm pupae for carp feed.

Ricefield carp culture in Japan once produced 140–247 kg/ha without supplementary feeding and 750–1 800 kg with supplementary feeding. In 1943, the annual production was over 4 400 tons; it fell to 479 tons in 1954. At present there is no harvest of common carp from rice fields. The main factors for decline are use of insecticides and herbicides, and loss of importance of carp to rice with increasing use of inorganic fertilizers.

With almost complete cessation of carp culture in rice fields, its intensive culture has started in irrigation ponds, running water ponds and floating net-cages. It is also carried on in small fish ponds.

Japanese carp production for 1973 totalled 26 344 tons derived as follows: irrigation ponds, 11 566 tons (44%); running-water ponds, 5 534 tons (21%); small fish ponds, 3 495 tons (13%); floating net-cages, 5 749 tons (22%).

This carp production is 41% of Japan's total production of cultured freshwater species (64 000 tons) which is, in turn, 6% of Japan's total capture and culture fisheries (1973). Carp production increased by 4·3 times from 1963 to 1973 while the total fish harvest of the country increased only 1·6 times during the same period.

Japan has 280 000 irrigation ponds totalling 110 800 ha. In 1973, 3 300 ha used for carp culture yielded 3·5 tons/ha. Intensive culture in such ponds (using aeration, floating piers for feeding, stocking in April-May with one-year-old fingerlings of 40–100 g at a rate of one fish/m^2 and feeding them four or five times a day with pelleted feed of silkworm pupae) produces marketable table carp of 800 g by autumn. Survival rate of carp stocked in irrigation ponds is 50–85%; feed efficiency, 50–75%. Carp from 500 to 800 g/m^2 (5–8 tons/ha) have been produced in irrigation ponds in Nagano.

Running-water ponds are usually 20–100 m^2 and 1·5 m deep. Inflow rate from streams is 280–420 l/second. Ponds are stocked in April at 3–11 kg/m^2 with 150 g fish one to two years old. Fed 15–20 times daily, they reach 800 g in autumn. Net production is 100–200 kg/m^2.

Small fish ponds are 900–3 000 m^2 with standing or slow water. One-year-old fingerlings of 80–120 g are stocked in April at 0·5–1 fish/m^2. They are fed intensively with artificial feed or silkworms. Survival rate is about 90%; feed efficiency about 60%. The fish grow to average 800 g. Harvest is 500–800 g/m^2.

Floating net-cage culture for carp (originated in 1951 and developed in lakes and irrigation ponds in 1964) uses cages, from 25 to 120 m^2 of 2 m depth, made of plastic net on bamboo frames, using drums as floats, with water depth maintained at about 1·5 m. Fingerlings of 50–120 g are stocked in the net-cages in April at 30 fish/m^3. They are fed four to five times daily. Survival rate is about 90%; feed efficiency is about 70%. The carp grow to 800 g and are harvested at a rate of 20–50 kg/m^3.

Recirculating tanks are also used but are not yet popular owing to high cost and necessity of use of specialized technicians. The effluent water circulates through gravel before returning to the tank. On one farm, the total volume of water used to cultivate 5 tons of carp is only 286 m^3 at 25–30°C. Fingerlings about 515 g totalling 2·25 tons are stocked in this volume for a 57 day culture period. Survival rate is 98·6%; feed efficiency 99%. Harvest is 4·12 tons of 957 g carp.

Silkworm production has declined with the development of synthetic fibres. White marine fish meal is scarce. One way to offset the problem of obtaining cheap animal protein for fish feeds is to increase the protein conversion rate in fish through genetic improvement. A crossing of yamato carp (a widely cultivated Japanese race) with mirror carp has increased feed efficiency 6%, and other useful F_1 hybrids by other crosses with German scaled carp are being developed.

Intensive feeding in fish culture has resulted in pollution problems. In some lakes the number of cages and their stocking will have to be regulated on the basis of lake water quality.

L'élevage de la carpe commune au Japon

Résumé

La carpe commune (*Cyprinus carpio*) est élevée depuis au moins 2 400 ans en Chine et 1 900 ans au Japon.

Son élevage intensif se pratique depuis longtemps dans les préfectures de Nagano, Gunma et Yamagata, qui se trouvent loin des côtes et sont donc mal approvisionnées en poisson de mer; de plus, elles disposaient jadis d'abondantes quantités de cocons de ver à soie pour le nourrissage.

Au Japon, le rendement de la rizi-carpiculture était autrefois de

140–247 kg/ha sans alimentation d'appoint, et de 750–1 800 kg/ha avec alimentation d'appoint. En 1943, la production annuelle a dépassé 4 400 tonnes; en 1954, elle est tombée à 479 tonnes. A l'heure actuelle, la récolte de carpes communes dans les rizières est pratiquement nulle. Ce déclin de la production s'explique principalement par le recours aux insecticides et aux herbicides et par la perte d'importance des carpes par rapport au riz, par suite du recours accru aux engrais minéraux. Avec la cessation presque complète de la carpiculture en rizières, on a entrepris l'élevage intensif dans des étangs d'irrigation, des étangs d'eau courante et des cages en filet, de type flottant. On élève également la carpe dans de petits étangs de pisciculture.

En 1973, la production japonaise de carpes a atteint le total de 26 344 tonnes, réparties comme suit: étangs d'irrigation—11 566 tonnes (44%); étangs d'eau courante—5 534 tonnes (21%); petits étangs de pisciculture—3 495 tonnes (13%); cages flottantes en filet—5 749 tonnes (29%).

Cette production de carpe représente 41% de la production japonaise totale de poisson d'élevage en eau douce (64 000 tonnes), laquelle a représenté elle-même en 1973 6% du total de la production halieutique du Japon (quantités capturées et élevées). Entre 1963 et 1973, la production de carpes a augmenté de 4,3 fois, tandis que la récolte totale de poisson du pays n'a augmenté que de 1,6 fois au cours de la même période.

Le Japon possède 280 000 étangs d'irrigation, qui ont une superficie totale de 110 800 ha. En 1973, 3 300 ha d'étangs utilisés pour la carpiculture ont donné un rendement de 3,5 tonnes/ha. La culture intensive dans de tels étangs (avec aération, pontons permettant le nourrissage du poisson, empoissonnement en avril-mai—à raison de 1 poisson/m^2—avec des carpillons d'un an pesant 40 à 100 g et nourrissage des sujets 4 ou 5 fois par jour avec des granulés ou des cocons de ver à soie) produit à l'automne suivant des carpes de consommation de taille marchande, pesant 800 g. Le taux de survie des carpes mises en place dans des étangs d'irrigation est de 50 à 85%; le coefficient d'efficacité alimentaire est de 50 à 75%. Une production de carpes atteignant 500–800 g/m^2 (5–8 tonnes/ha) a été obtenue dans des étangs d'irrigation de Nagano.

Les étangs d'eau courante ont ordinairement 20 à 100 m^2 de superficie et 1,5 mètres de profondeur. Le débit des courants d'eau admis dans les étangs est de 280–420 litres/seconde. Les étangs sont empoissonnés en avril avec des carpillons de un à deux ans pesant 150 g et à raison de 3 à 11 kg/m^2. Alimentés 15 à 20 fois par jour, ces juvéniles atteignent le poids de 800 g à l'automne. La production nette est de 100–200 kg/m^2.

Les petits étangs de pisciculture dont l'eau est stagnante ou à courant lent, ont une superficie de 900 à 3 000 m^2. On les empoissonne au mois d'avril avec des juvéniles de un an, pesant 80 à 120 g, à raison de 0,5–1 poisson/m^2. Les carpillons sont nourris intensivement avec des aliments artificiels ou des vers à soie. Le taux de survie est d'environ 90% et le coefficient d'efficacité alimentaire d'environ 60%. Les poissons atteignent en moyenne le poids de 800 g. Le rendement est de 500 à 800 g/m^2.

Pour l'élevage de la carpe dans des cages en filet de type flottant (entreprise en 1951 et développé dans les lacs et les étangs d'irrigation en 1964), on utilise des cages de 25 à 120 m^2 de superficie et de 2 m de profondeur, constitués de filets de plastique tendus sur des cadres de bambou, et munies de barillets comme flotteurs; la profondeur de l'eau est maintenue à environ 1,5 m. Des juvéniles de 50 à 120 g sont mis en place dans ces cages au mois d'avril, à raison de 30 poissons par m^3. On les nourrit 4 à 5 fois par jour. Le taux de survie est d'environ 90%; le coefficient d'efficacité alimentaire est d'environ 70%. Les carpes atteignent le poids de 800 g et le rendement obtenu est de 20 à 50 kg/m^3.

On utilise également des réservoirs à recirculation, mais ils ne sont pas encore très populaires en raison de leur coût élevé et de la nécessité de faire appel à des techniciens spécialisés. Les eaux résiduaires circulent à travers du gravier avant de retourner au réservoir. Dans un établissement piscicole, le volume total de l'eau utilisée pour élever 5 t de carpes n'est que de 286 m^3 à la température de 25–30°C. Des juvéniles d'environ 515 g, pesant au total 2,25 tonnes, sont mis en place dans ce volume d'eau pour une période d'élevage de 57 jours. Le taux de survie est de 98,6%; le coefficient d'efficacité alimentaire est de 99%. On récolte ainsi 4,12 tonnes de carpes de 957 g.

La production de ver à soie a fléchi parallèlement à l'expansion des fibres synthétiques. La farine de poissons blancs marins est rare. Comme moyen de surmonter le problème de l'obtention de protéines animales à bon marché pour l'alimentation du poisson, on accroît le taux de conversion protéique du poisson par amélioration génétique. Grâce à un croisement de carpe yamato (race japonaise dont l'élevage est très répandu) avec la carpe miroir, on a accru le coefficient d'efficacité alimentaire de 6%; on met actuellement au point d'autres intéressants hybrides F_1 en effectuant d'autres croisements avec la carpe à écailles allemande.

Le nourrissage intensif utilisé en pisciculture a entraîné des problèmes de pollution. Dans certains lacs, le nombre de cages et leur densité d'empoissonnement devront être réglementés en fonction de la qualité de l'eau.

Cultivo de carpa común en el Japón

Extracto

La carpa común (*Cyprinus carpio*) se ha cultivado en China desde hace unos 2 400 años y en el Japón desde hace 1 900.

El cultivo intensivo de esta especie se ha practicado durante mucho tiempo en las prefecturas de Nagano, Gunma y Yamagata, que, alejadas del mar y, por tanto, mal abastecidas de pescado marino, disponían en una ocasión de abundantes ninfas de gusano de seda para alimentar a las carpas.

El cultivo de carpas en arrozales producía en el Japón 140–247 kg/ha sin alimentación suplementaria y 750–1 800 kg con piensos suplementarios. En 1943 la producción anual fue superior a 4 400 toneladas, y en 1954 disminuyó a 479 toneladas. En la actualidad no se cultivan carpas en los arrozales. Las causas principales son el empleo de insecticidas y herbicidas y la menor importancia de la carpa para el arroz al aumentar el empleo de fertilizantes inorgánicos.

Con el cese casi completo de el cultivo de carpas en los arrozales, ha dado comienzo su cultivo intensivo en estanques de riego, estanques de agua corriente y jaulas flotantes. También se usan pequeños estanques piscícolas.

La producción de carpas en el Japón fue en 1973 de 26 344 toneladas, así distribuidas: estanques de riego, 11 566 toneladas (44%); estanques de agua corriente, 5 534 toneladas (21%); pequeños estanques piscícolas, 3 495 toneladas (13%); jaulas flotantes, 5 749 toneladas (22%).

La producción de carpas representa el 41% de la producción japonesa total de especies cultivadas de agua dulce (64 000 toneladas), que, a su vez, constituye el 6% del producto total pesquero y piscícola (1973). La producción de carpas aumentó en 4,3 veces desde 1963 a 1973, mientras que la producción pesquera total del país aumentó sólo en un 1,6 veces durante el mismo período.

Japón cuenta con 280 000 estanques de riego, con un total de 110 800 ha. En 1973, las 3 300 ha utilizadas para el cultivo de carpas produjeron 3,5 toneladas/ha. El cultivo intensivo en esos estanques (utilizando sistemas de aireación y muelles flotantes para distribuir los alimentos, sembrando en abril-mayo jaramugos de un año (40–100 g) a razón de un pez/m^2 y alimentándolos cuatro o cinco veces al día con piensos granulados o ninfas de gusano de seda) produce en el otoño carpas para consumo de 800 g. La tasa de supervivencia de las carpas sembradas en estanques de riego es del 50 al 85%, y la eficiencia de conversión de alimentos de 50–65%. En los estanques de riego de Nagano se han producido carpas de 500–800 g/m^2 (5–8 toneladas/ha).

Los estanques de agua corriente tienen en general de 20 a 100 m^2 y 1,5 m de profundidad. El caudal de entrada es de 280–420 l/segundo. Los estanques se siembran en abril, a densidades de 3–11 kg/m^2, con peces de 150 g y de uno a dos años de edad. Alimentándoles de 15 a 20 veces al día, alcanzan para el otoño pesos de 800 g. La producción neta es de 100–200 kg/m^2.

Los pequeños estanques piscícolas, con agua estancada o de flujo lento, tienen superficies de 900 a 3 000 m^2. En abril se siembran jaramugos de un año de 80–120 g, a razón de 0,5–1 pez/m^2. Se alimentan intensivamente con piensos artificiales o gusanos de seda. La tasa de supervivencia es de aproximadamente 90%, y la eficiencia de aprovechamiento de los alimentos del 60%. Los peces crecen hasta una talla media de 800 g. La producción es de 500–800 g/m^2.

Para el cultivo de carpas en jaulas flotantes (comenzado en 1951 y desarrollado en 1964 en lagos y estanques de riego) se utilizan jaulas de 25 a 120 m^2 y 2 m de altura hechas de red de plástico sobre un marco de bambú y utilizando bidones como flotadores. La profundidad del agua se mantiene en torno a 1,5 m. En abril se colocan en las jaulas jaramugos de 50–120 g, a razón de 30 peces/m^3. Se les alimenta de 4 a 5 veces al día. La tasa de supervivencia es de 90% y la eficiencia de conversión de los alimentos del 70%. Las carpas alcanzan un peso de 800 g y la producción es del orden de 20–50 kg/m^3.

Se utilizan también tanques con agua recirculada, pero no son aún populares, debido a lo elevado de los costos y a la necesidad de utilizar técnicos especializados. El agua que afluye de los tanques pasa por unos estratos de gravilla antes de volver a ellos. El volumen total de agua utilizada en una granja para cultivar 5 toneladas de carpas es de 286 m^3, a 25–30°C. Se siembran peces de unos 515 g, por un total de 2,25 toneladas, y se cultivan durante 57 días. La tasa de supervivencia es del 98,6% y la eficiencia de conversión de alimentos de 99%. El rendimiento es de 4,12 toneladas de carpas de 957 g.

La producción de gusanos de seda ha disminuido con el desarrollo de las fibras sintéticas. La harina de pescado marino blanco es escasa. Una de las formas de resolver el problema de disponer de alimentos proteicos baratos para piensos para los peces es aumentar la tasa de conversión de proteínas de los peces mediante mejora genética. Un cruce de carpa yamato (raza japonesa cuyo cultivo está muy extendido) con carpa espejo ha permitido aumentar la eficiencia de conversión de alimentos en un 6% y se están preparando otros híbridos útiles F_1 mediante cruces con carpa alemana.

La alimentación intensiva en la piscicultura ha causado problemas de contaminación. En algunos lagos será necesario regular el número de jaulas y el número de peces de cada una de ellas teniendo en cuenta la calidad de las aguas.

1 Historical

The common carp (*Cyprinus carpio*), native to Central

Asia, has been under domestication longer than any other fish in the world. It has been cultivated for at least 2 400 years in China and for 1 900 years in Japan. In Japan, intensive culture of the common carp has long been practised in Nagano, Gunma and Yamagata Prefectures. There are two principal reasons for this. Firstly, the three prefectures are located far from the sea and hence have a poor supply of sea fish. Secondly, due to the abundant availability of silkworm pupae as an artificial diet for carp, the culture of this species became popular.

Until about 1945, carp were cultivated mainly in the rice fields as an additional source of income for farmers. According to Kawajiri (1951), carp fingerlings stocked in the rice fields in spring reached a body weight of 400–750 g in the autumn of the second or third years. Fish production in the rice fields with supplementary feeding was in the order of 750–1 800 kg/ha. Without supplementary feeding, it fell to 140–247 kg/ha. The carp produced in rice fields were consumed only in the districts where they were produced as an important protein source for the farmers.

In 1943, the annual country-wide harvest of carp from rice fields was over 4 400 tons and carp culture with rice was intensified during the second world war. After the war, however, the harvest of carp from rice fields fell to 937 tons in 1949 with a further decline to only 479 tons in 1954. At present, there is no harvest of common carp from rice fields. The main factor responsible for this decline in carp harvest was the use of insecticides, such as parathion and dieldrin, which are very toxic to fish in great dilution, and selective herbicides like PCP-Na which is very harmful to fish even in extreme dilution. In addition, with increasing use of inorganic fertilizers, such as ammonium sulphate, the practice of carp culture in rice fields lost its importance. Hence, Japanese farmers lost interest in fish cultivation in rice fields. (Further information on carp culture in Japanese rice fields can be found in Hickling, 1971).

With almost complete cessation of common carp culture in rice fields, its culture began in irrigation ponds, running-water ponds and floating net-cages. The success of carp culture in these water bodies is based on intensive artificial feeding. In 1973, production of cultured carp in Japan was, in total, 26 344 tons. Such increased production is the result of the use of nutritious artificial pellet diets, automatic feeders and aerators. Furthermore, high production of carp helped it reach consumers in large cities away from the producing districts. With a steep rise in national income, people indulged in a diversity of eating habits which resulted also in increased demand for carp as a different food.

2 Production of common carp compared with other freshwater fish

According to statistics issued by Japan, Ministry of Agriculture (1973), the annual production of capture and culture fisheries in the sea and fresh water in Japan during 1973 was of the order of about 10 700 000 tons (Fig. 1). Of this total, the culture fishery in fresh water contributed only 64 000 tons or 0·6%. The annual harvests of cultured freshwater species in 1973 were as follows: carp, 26 000 tons; trout (*Salmo*) 16 000 tons; eel (*Anguilla*) 15 000 tons; ayu (*Plecoglossus altivelis*) 4 000 tons; and others (such as Crucian carp, *Carassius carassius*) 3 000 tons. The annual harvest of cultivated carp increased by 4·3

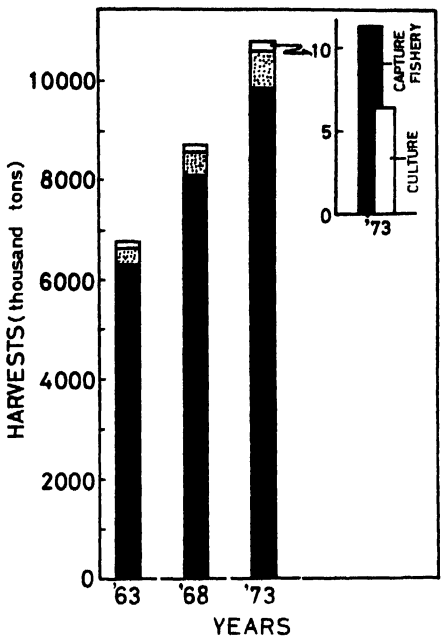


Fig 1. Total harvest of fish in Japan. The open space in the bar shows both culture and capture fisheries in inland waters. The dotted space in the bar shows the culture fishery in the sea. The solid space in the bar shows the capture fishery in the sea

times from 1963 to 1973 (Fig. 2). However, the total fish harvest in Japan from both capture and culture fisheries increased by only 1·6 times during the same period. These data indicate that carp is the most important fish for cultivation in the inland waters of Japan.

In 1973, the annual harvest of carp from leading prefectures was as follows: Nagano, 5 100 tons; Ibaragi, 3 200 tons; Gunma, 3 000 tons; and Akita 2 400 tons. The high production in Nagano Prefecture can be attributed to the abundance of irrigation ponds and culture in floating net-cages used extensively in Lake Suwa.

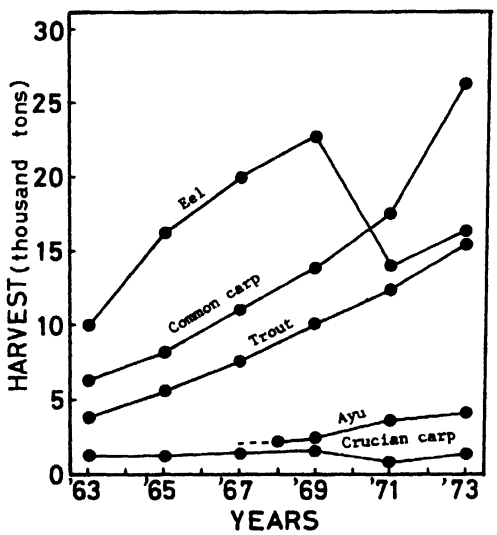


Fig 2. Harvest of pond-cultivated fish in the inland waters of Japan

3 Status of carp culture

3.1 *Irrigation ponds*

In Japan there are 280 000 irrigation ponds having a total area of about 110 800 ha. Until about 1953, the great majority of the irrigation ponds were not used for fish culture employing intensive artificial feeding. Small ponds were sometimes stocked with carp fingerlings but neither

supplementary feeding nor pond fertilization was practised. In such ponds where fingerlings were stocked in spring at the rate of 50–70 kg/ha only 250–300 kg/ha were harvested in the autumn. Since 1954, many irrigation ponds have been utilized for carp culture by intensive artificial feeding. In 1973, 11 566 tons of carp were harvested from 3 300 ha of irrigation ponds—a production of about 3·5 tons/ha. This is about 44% of the total cultivated carp crop in Japan.

The size of irrigation ponds used for carp culture varies from 0·5 to 20 ha in area. The outlet of each pond is equipped with wire netting to prevent the escape of fish. The majority of the ponds are provided with floating piers for feeding and with aeration pumps. In almost all cases, the water in these irrigation ponds is standing, and usually the quantity and quality of the water decreases during the dry season.

Fingerlings for stocking are produced in small fishponds of about 0·5–1·0 ha which have been fertilized with chicken droppings. The fingerlings are kept in these ponds until spring of the second or following year when they weigh from 40 to 100 g each. From April to May, these yearlings are stocked in irrigation ponds at the rate of one fish per m^2. They are fed intensively with artificial pelleted feed or silkworm pupae four to five times a day; this feeding continues until harvest in the autumn. During this period, the fish reach an average weight of 800 g, a marketable size for table carp in Japan. Recently, the Shioda Co-operative Association of Carp-culture in Nagano Prefecture, the best known association in Japan for carp culture in irrigation ponds, produced common carp from 500 to 800 g/m^2, *ie*, from 5 to 8 tons/ha. Thus, the harvests following supplementary feeding are over 20 times those in Japanese carp culture without supplementary feeding. Typical examples of the results of carp culture in irrigation ponds are given in Table I. The survival rate of carp stocked in irrigation ponds varies from 50 to 85% while feed efficiency varies from 50 to 75%.

TABLE I
THE RESULTS OF CARP CULTURE IN IRRIGATION PONDS IN NAGANO PREFECTURE[1]

Number of ponds	*1*	*2*	*3*	*4*
Area (ha)	1·1	1·5	1·2	5·3
Stocked fish				
Total weight (kg)	1 700	830	750	3 200
Average body weight (g)	63	43	70	64
Harvested fish				
Total weight (kg)	17 600	9 300	7 000	21 000
Average body weight (g)	860	765	780	790
Feed efficiency (%)	65·5	66·8	74·2	53·0
Survival rate (%)	75·8	63·0	83·8	53·2

[1] Data from Tominaga (1967)

3.2 *Running-water ponds*

In places where there is abundant water supply, carp are cultivated in running-water ponds. This method of carp culture is fundamentally based on and originated from the wintering practice used when carp were harvested from rice fields in autumn. Present day running-water ponds are stocked in the spring with fingerlings at a very high density. The carp are then fed intensively with artificial feeds until they reach marketable table size. The techniques for fingerling production are the same as those used in irrigation ponds. Running-water carp-culture ponds are generally 20–100 m^2 in area and about 1·5 m deep. The inflow rate of water (from a stream) varies from 280 to 420 l/s.

In April, running-water ponds are stocked with fingerlings at the rate of 3–11 kg/m^2. The average weight of a fish which is one to two years of age at the time of stocking is 150 g. The fish are fed intensively 15 to 20 times a day. In autumn, these fish reach an average weight of about 800 g. The net production of carp in running water is 100–200 kg/m^2. Some examples of carp culture in running-water ponds are given in Table II.

TABLE II
THE RESULTS OF CARP CULTURE IN RUNNING-WATER PONDS[1]

Number of ponds	*1*	*2*	*3*	*4*
Area (m^2)	47	42	28	89
Stocked fish				
Total weight (kg)	700	413	289	700
Average body weight (g)	82·5	82·5	82·5	82·5
Harvested fish				
Total weight (kg)	10 314	4 313	3 000	8 636
Feed efficiency (%)	37·8	38·5	37·5	41·1

[1] Data from Chiba (1965)

In 1973, 5 534 tons of carp were produced from running-water ponds in Japan. This amounts to 21% of the total harvest of carp from culture fisheries. In Nagano Prefecture alone, the annual harvest in 1973 from running-water ponds was 1 490 tons, *ie*, 27% of the total carp production from running water in Japan.

3.3 *Small fishponds*

The small fishponds which are used for carp culture are from 900 to 3 000 m^2. These ponds have standing water in most cases but even if the pond does have a partially fluvial condition, the rate of water renewal is very slow. In April, one-year-old fingerlings having an average weight of 80–120 g are stocked in the ponds at a density of 0·5–1·0 fish/m^2. Intensive feeding with pelleted artificial feed or silkworm pupae is continued until harvest in autumn. The rate of survival is about 90% and the fish grow to an average of 800 g. The average feed efficiency is about 60%. The harvest amounts to 500 to 800 g/m^2.

In other words, the culture techniques and harvest rates in small fishponds are almost the same as those in irrigation ponds. By this method of culture, the annual harvest in Japan during 1973 was 3 495 tons, *ie*, 13·3% of the total production of carp by culture methods.

3.4 *Floating net-cages*

In 1964, techniques for the culture of carp in net-cages developed in some lakes and large irrigation ponds in Japan. The technique of carp culture in net-cages was originally established in 1951 by the Miyazaki Prefectural Fisheries Experimental Station, and from there spread to lakes Suwa and Kasumigaura and to large irrigation ponds.

Cages vary in size from 25 to 120 m^2, with a depth of about 2 m. The cage is made of plastic netting supported on bamboo frames with drums as floats. The water depth is maintained at about 1·5 m. The cage is kept in position with the help of pegs fixed to the pond bottom.

Fingerlings for stocking are procured from irrigation or small fishponds. In April, the fingerlings which weigh 50–120 g are stocked in the net-cage at the rate of 30 fish/m^3. They are fed intensively four to five times a day. The carp grow to a weight of about 800 g and are harvested at the

rate of 20–50 kg/m^3. Feed efficiency is about 70%, and survival rate is about 90%. Examples of this type of carp culture are given in Table III.

In 1973, the annual production of carp in net-cages in Japan was of the order of 5 749 tons, *ie*, 21·8% of the total production of the country's carp culture fishery. The production according to major prefectures was: Ibaragi, 53·1; Nagano, 17·6; and Shiga, 7·6%.

TABLE III
THE RESULTS OF CARP CULTURE IN FLOATING NET-CAGES IN LAKE SUWA[1]

Number of net-cages	*1*	*2*	*3*
Area (m^2)	81	81	13·2
Stocked fish			
Total weight (kg)	238·5	205	91
Average body weight (g)	48·6	50	121
Harvested fish			
Total weight (kg)	4 077	2 546	764
Average body weight (g)	927	740	1 031
Feed efficiency (%)	72·7	63·6	71·8
Survival rate (%)	89·8	84·6	97·7

[1] Data from Kurihara (1967)

3.5 *Recirculation systems*

In the recirculating tank method the water that has been used for fish culture circulates from the fish tank through gravel filters and is aerated before being returned to the tank. Fish are fed intensively with artificial feeds. The fish faeces are decomposed by the bacteria which develop on the gravel surfaces. This method of fish culture has not yet become popular in Japan, because of the high cost of the equipment and the necessity of using specialized technicians.

Mr. Motokawa's Fish Farm in Takasaki City, Gunma Prefecture, is well known for its excellent results with carp culture in recirculating tanks. On this farm the total volume of water used to cultivate five tons of fish is only 286·3 m^3 held at 25–30°C. Carp fingerlings with an average weight of about 515 g totalling 2·25 tons are stocked in this volume of water. In 57 days of culture, 4·12 tons of fish, each weighing about 957 g, are harvested. The feed efficiency is 99%. The survival rate is 98·6%.

4 Problems of carp culture

4.1 *Alleviating the scarcity of protein for artificial feeds*

One of the most important problems in fish culture is coping with the shortage of cheap animal protein to be used in artificial fish feeds. As mentioned above, silkworm pupae constitute an important protein surce for supplemental feeding of carp in Japan. Recently, however, silkworm production has decreased decidedly because of the development of synthetic fibres. With the decrease in silkworm production, pelleted artificial feeds have come into the market. The costs of these new feeds have contributed to the steep rise in production costs for carp. The protein source for pelletized diets for carp comes from white fishmeal, and the marine resources which supply this fishmeal cannot meet the increased demand for pelletized feed. It is necessary, therefore, to find cheaper sources of protein to replace the pupae or white fishmeal.

Another way to tackle the problem is to try to increase the protein conversion rate in fish through genetic improvement. As is well known, there are many races of carp throughout the world. We have performed experiments using some races of Japanese common carp, such as the widely cultivated yamato carp, the mirror carp, and the German scaled carp, transplanted from Europe in 1968. The survival rate, growth rate, feed conversion efficiency and morphological characteristics of these races were compared. The fish were cultivated under three different environmental conditions: (*i*) in running-water ponds with artificial feeding; (*ii*) in standing-water ponds with artificial feeding; and (*iii*) in fertilized ponds without artificial feeding. It was found that mirror carp had a higher growth rate as well as a greater feed efficiency than the yamato carp under all three environmental conditions. However, the survival rate in mirror carp was remarkably low as compared to that of yamato carp because it is highly susceptible to *Gyrodactylus* infection up to age one.

Our next experiment was to obtain hybrid progenies which have economical characters of both parental races. F_1 hybrids were artificially produced from 10 combinations between races of Japanese and German carps. One-month-old fry, weighing 3·5 g, in each hybrid combination were cultivated for 10 months at a controlled water temperature of 26° (±1°) C. A hybrid combination between female yamato carp and male mirror carp showed definite heterosis, *ie*, the growth rate of F_1 hybrids was much higher than in either of the parents (Fig. 3). Furthermore, their survival rate was not only better than that of mirror carp but also slightly higher than that of yamato carp. A 10 month rearing of F_1 hybrids showed a higher rate of feed conversion efficiency than either of the parent races. The average value of feed conversion efficiency of the F_1 generation was 85·8% against 79·8% in yamato and 82% in mirror carp (Table IV). In other words, crossing of yamato carp with mirror carp increased the feed efficiency at the average rate of 6%. If all Japanese farmers were to cultivate such F_1 hybrids, the feeds required for carp culture in Japan would

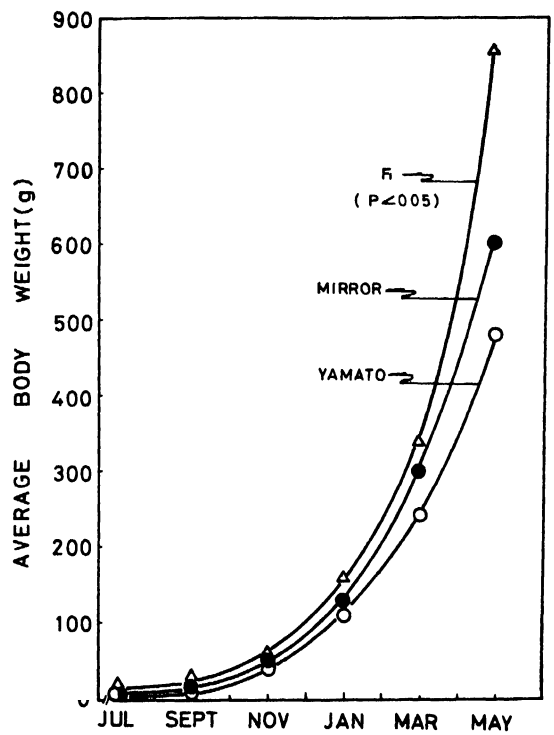


Fig 3. Growth curves of F_1 hybrids between female yamato carp and male mirror carp and their parent races

TABLE IV
RESULTS OF A 10 MONTH CULTURE OF F_1 HYBRIDS BETWEEN YAMATO AND GERMAN CARPS AND THEIR PARENTAL RACES

Crosses	*Average body weight of harvested fish* (g)	*Average feed efficiency* (%)	*Survival rate* (%)	*Heterosis-potential rate* (%)
Yamato ♀				
x Yamato ♂	482·0	79·8	80·0	
x Mirror ♂	855·5	85·8	84·4	+57·6
x German scaled ♂	738·2	84·3	77·7	+56·2
Mirror ♀				
x Mirror ♂	603·8	82·0	72·5	
German scaled ♀				
x German scaled ♂	463·2	77·2	76·3	

be reduced by about 3 000 tons a year. This figure was calculated on the basis that the total production of common carp cultured in Japan is 26 000 tons a year and feed conversion efficiency 70%.

Similar useful F_1 hybrids were obtained by crossing female yamato and male German scaled carp. In the future it is planned to cultivate F_1 hybrids of yamato, mirror and German scaled carps in several Japanese farms.

4.2 *Pollution by fish culture pond drainage*

In fish culture with intensive feeding, pollution problems occur from pond drainage. The outflowing water contains abundant wastes from the fish which raise the biological oxygen demand of rivers and lakes. In irrigation ponds, it is common to observe that the upper water layer has an abundance of phytoplankton while the lower layer contains decomposing organic matter. When the fish are harvested in the autumn, the water from such ponds is drained off into the rivers. It has recently been claimed that carp culture in floating net-cages is responsible for eutrophication in lakes Suwa and Kasumigaura. In future, the number of cages and their stocking with fish in these lakes must be regulated on the basis of the lake's water quality.

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Culture of Male *Tilapia mossambica* Produced Through Artificial Sex Reversal

Rafael D. Guerrero III

Abstract

Experiments were conducted to compare production and reproduction of methyltestosterone-treated and untreated fish at different stocking rates in fertilized ponds, determine the effectiveness of methyltestosterone fed at varying durations for inducing sex reversal of sexually undifferentiated fry, and determine the cost of sex reversal treatment. Fry of *Tilapia mossambica* were treated with 30 µg of methyltestosterone per gramme feed in concrete tanks for two, three and four weeks. Control fish were stocked in 0·1 ha ponds at 10 000/ha and 20 000/ha while treated fish were stocked at 10 000/ha, 15 200/ha, 20 000/ha and 30 000/ha. Higher standing crops and larger individual weights were attained with treated fish compared with untreated fish at comparable stocking rates. Hormone treatment for two, three and four weeks produced 69, 93 and 98% males, respectively. Control fish reproduced at a greater rate than the treated fish. The cost for feed, solvent and hormone needed to treat 1 000 fish for four weeks was US$ 0·84.

Elevage de *Tilapia mossambica* mâles produits par inversion artificielle du sexe

Résumé

Des expériences ont été réalisées à trois fins: comparer la production et la reproduction de poissons traites ou non au méthyl-testostérone, à différentes densités dans des étangs fertilisés; déterminer l'efficacité de l'administration de méthyl-testostérone dans l'alimentation pendant des durées variables pour induire l'inversion du sexe chez des alevins sexuellement indifférenciés; déterminer le coût du traitement d'inversion sexuelle. Des alevins de *Tilapia mossambica*, é leués en cuves de béton, ont reçu de la nourriture contenant 30 µg/g de méthyl-testostérone pendant deux, trois ou quatre semaines respectivement. Les spécimens témoins ont été maintenus dans des étangs de 0,1 ha à raison de 10 000/ha et 20 000/ha alors que la densité des poissons traités était de 10 000/ha, 15 200/ha, 20 000/ha et 30 000/ha. Il a été possible d'obtenir pour une même densité des biomasses plus importantes et des poids individuels plus élevés avec les poissons traités. Les traitements hormonaux d'une durée de 2, 3 et 4 semaines ont respectivement produit 69, 93 et 98% de mâles. Les poissons témoins se sont reproduits plus fréquemment que les poissons traités. Le coût des aliments, du solvant et des hormones nécessaires pour traiter 1 000 poissons pendant 4 semaines s'est élevé à US$ 0,84.

Cultivo de machos de *Tilapia mossambica* producidos por inversión artificial del sexo

Extracto

Se realizaron experimentos para: comparar la producción y la reproducción de peces tratados con metiltestosterona y sin tratar, en estanques fertilizados repoblados a diversos indices de densidad; determinar la eficacia del suministro de metiltestosterona durante periodos diversos para inducir la inversión sexual de jaramugos aún indiferenciados sexualmente y determinar el costo del tratamiento para la inversión de sexo. Se trató a jaramugos de *Tilapia mossambica* en tanques de hormigón con 30 µg de metiltestosterona por cada gramo de pienso durante dos, tres y cuatro semanas. Los peces testigo se sembraron en estanques de 0,1 hectáreas a razón de 10 000/ha y 20 000/ha, mientras los peces tratados se echaron en estanques a razón de 10 000/ha, 15 200/ha, 20 000/ha y 30 000/ha. Con tasas comparables de densidad, los peces tratados dieron rendimientos y pesos individuales mayores que los peces sin tratar. El tratamiento hormonal durante dos, tres y cuatro semanas produjo, respectivamente, 69, 93 y 98% de machos. Los peces testigo se reprodujeron a un ritmo mayor que los peces tratados. El costo de los piensos, los solventes y las hormonas necesarias para tratar 1 000 peces durante cuatro semanas fue de $EE.UU. 0,84.

1 Introduction

Tilapia are extensively cultured in warmwater areas of the

world as food fishes. A major obstacle in their culture is unwanted reproduction that results in overcrowding and stunted growth. Three methods have been demonstrated to be effective in producing faster-growing male tilapia and eliminating reproduction. These methods are monosex culture (Hickling, 1968), hybridization (Hickling, 1960) and sex reversal (Clemens and Inslee, 1968; Guerrero, 1975).

Clemens and Inslee (1968) induced functional sex reversal of XX females in *Tilapia mossambica* with treatment of 30 μg methyltestosterone per gramme of feed for 69 days. Guerrero (unpublished data) obtained 100% male *T. mossambica* by treating sexually undifferentiated fry with 30 μg methyltestosterone per gramme feed for 37 days.

Experiments were conducted to : (*i*) compare production and reproduction of methyltestosterone treated and untreated fish at different stocking rates in fertilized ponds, (*ii*) to determine the effectiveness of methyltestosterone administered at varying durations for inducing sex reversal of *T. mossambica* fry, and (*iii*) to determine the cost of sex reversal treatment.

2 Experimental procedure

Approximately 15 000 *T. mossambica* fry, measuring 9–11 mm total length, were collected from a concrete breeding pool. Fry were given static prophylactic treatment of 1% NaCl for 30 minutes prior to counting and stocking in ten 250 l circular tanks inside a building.

The aerated tanks were each stocked with 1 500 fry. Ten batches of fry were treated as follows: three were given feed without hormone, four were given feed treated with 30 μg of methyltestosterone (MT-30) per gramme feed (40% fine rice bran, 30% tilapia flour, 30% brewer's yeast) for four weeks, two were treated with MT-30 for three weeks, and one batch was treated with MT-30 for two weeks.

Fry were fed at rates of 3% of body weight given four times daily six days a week for the first two weeks and 2·5% of body weight four times daily for the last two weeks.

Water in the tanks was replaced every two days. Fry in each tank were sampled weekly to adjust the feeding rate. An indefinite prophylactic treatment using 1% NaCl was carried out every week to control *Trichodina* sp.

After two weeks, three weeks and four weeks of MT-30 treatment, fish were stocked in five 0·1 ha ponds as follows: one pond with 1 000 fish treated with MT-30 for four weeks, one with 1 520 fish treated for four weeks, one with 3 000 fish treated for four weeks, one with 1 000 fish treated for two weeks, and one with 2 000 fish treated for three weeks. Control fish were stocked in two other ponds with 1 000 and 2 000 each.

Ponds were fertilized with ammonium phosphate (16–20–0) on platforms at a rate of 50 kg/ha biweekly. Water depth was maintained at 60–70 cm. The experiment was terminated after 90 culture-days. At the end 100 fish per pond were randomly selected and individually sexed and weighed. The large fish were counted and the number of juveniles from reproduction were estimated in each pond.

To determine the cost of sex reversal treatment, the expenses for feed, solvent and hormone needed to produce 1 000 treated fry were computed. Other costs such as labour, water, fertilizer, depreciation of equipment and electricity were not included.

3 Results and discussion

A summary of the production of control and methyltestosterone-treated *T. mossambica* is presented in Table I. It is evident that hormone-treated fish yielded higher standing crops than the controls at corresponding stocking rates. Treated fish stocked at 10 000/ha and 20 000/ha attained marketable size (weight = 50 g) after 90 days of culture while control fish at similar rates did not. These findings indicate growth superiority and yield advantage of treated fish over untreated ones. Recovery rates of treated and control fish stocked at the same time appeared to be comparable.

In the pond stocked with 20 000/ha of fish treated with MT-30 for three weeks, 898 *T. mossambica* and 714 *T. zillii* were recovered. Fry of *T. zillii* were inadvertently mixed with those of *T. mossambica* during treatment and at stocking. Sex reversal treatment did not seem effective for *T. zillii*, and the only juveniles found were *T. zillii*.

Data presented in Table II show that the highest percentage of males was achieved with methyltestosterone treatment for four weeks. The percentage of males decreased with shortening of the treatment period. The results indicate that a treatment period of four weeks is sufficient to produce at least 95% males under the conditions of the experiment. Guerrero (1975) obtained 97% and 100% males respectively, through treatment with methyltestosterone and ethynyltestosterone at 30 μg/g feed for 18 days in *T. aurea*. Effectiveness of the sex reversal treatment is apparently influenced by potency of the hormone, duration of treatment, treatment conditions and species. The estimated number of *T. mossambica* juveniles from reproduction was greatest among the controls while lowest and absent in the groups treated with MT-30 for four and three weeks.

TABLE I

A SUMMARY OF STOCKING, RECOVERY AND PRODUCTION DATA FOR TREATED AND CONTROL GROUPS OF *Tilapia mossambica* CULTURED FOR 90 DAYS

Treatment	*No. fish stocked/ ha*	*Per cent recovery*	*Mean weight per fish (g)*	*Standing crop[e] (kg/ha)*
Control	10 000	95	29	276
Control	20 000	96	25	480
MT-30[a]	10 000	90	60	540
MT-30[a]	15 200	86	42	542
MT-30[a]	30 000	96	26	749
MT-30[b]	20 000	81[d]	70	629[f]
MT-30[c]	10 000	87	53	461

[a] Four-week treatment
[b] Three-week treatment
[c] Two-week treatment
[d] *T. mossambica* and *T. zillii* combined
[e] Reproduction not included
[f] *T. mossambica* only

TABLE II
PER CENT MALE AND ESTIMATED NUMBER OF JUVENILES FROM REPRODUCTION OF *Tilapia mossambica* CULTURED IN SEVEN PONDS

Treatment	*% male*	*No. of juveniles from reproduction*
Control	74	4 651
Control	56	2 400
MT-30[a]	95	548
MT-30[a]	95	3
MT-30[a]	98	4
MT-30[b]	93	0
MT-30[c]	69	2 090

[a] Four-week treatment
[b] Three-week treatment
[c] Two-week treatment

The computed cost for feed, solvent (alcohol) and methyltestosterone to treat 1 000 fry for four weeks was US$ 0·84. This suggests the economic feasibility of applying the sex reversal method on a commercial scale.

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Effects of High Density Culture and Form of Feed on Reproduction and Yield of *Tilapia aurea*

R. Allison, R. O. Smitherman and J. Cabrero

Abstract

Tilapia aurea were cultured for 114 days in 2·7 × 7·3 × 0·76 m (0·002 ha) concrete ponds. Triplicated treatments included *T. aurea* stocked at: 400/pond and fed pelleted feed; 200/pond with pelleted feed; 200/pond with non-pelleted feed of the same formulation; and 100/pond with pelleted feed. Fish were fed daily, six days/week, at rates varying from 5 to 2% of body weight. Fish were sampled at four-week intervals for adjustment of feeding allowance. All ponds were filled with well water, which was aerated with 5 hp air blower. Additional water was only added to replace losses due to evaporation and seepage.

Average net yields and feed conversions were equivalent to 17 307 kg/ha and 1·56, 12 151 kg/ha and 1·14, 10 581 kg/ha and 1·27, and 9 998 kg/ha and 0·92 for the four treatments respectively. Yield with the higher stocking density was significantly greater than in all other treatments, but feed conversion was significantly poorer. Differences between net yields and feed conversions of the two treatments with pelleted and non-pelleted feed were not significant. Average numbers of young produced in the four treatments were equivalent to 38 383, 99 146, 149 188 and 222 942/ha for the four treatments respectively. The numbers of young produced in the two treatments stocked with 200 tilapia/pond were not significantly different, but the overall treatment means indicated that the non-pelleted form of feed was more conducive to fry survival and production.

Effets de la forte densité et de la forme de l'aliment sur la reproduction et le rendement de *Tilapia aurea*

Résumé

On a procédé à l'élevage de *Tilapia aurea* pendant 114 jours dans des bassins en béton de 2,7 × 7,3 × 0,76 m (0,002 ha). Des traitements triples ont été appliqués aux stocks ci-après: 400 tilapias par bassin nourris avec des granulés; 200 tilapias par bassin nourris avec des granulés et 200 par bassin dont la nourriture de même fomulation n'était pas granulée; 100 tilapias par bassin nourris avec des granulés. L'alimentation était effectuée une fois par jour et six jours par semaine, à des taux variant de 5–2% de poids vif. Le poisson était échantillonné à 4 semaines d'intervalle aux fins d'ajustement de la ration alimentaire. Tous les bassins étaient remplis d'eau de pluie, aérée avec un ventilateur d'une puissance de 5 hp. On n'a ajouté d'eau que pour compenser les pertes dues à l'évaporation et à l'infiltration.

Les rendements nets et les taux de conversion alimentaire ont atteint 17 307 kg/ha et 1,56; 12 151 kg/ha et 1,14; 10 581 kg/ha et 1,27; et 9 998 kg/ha et 0,92 pour les quatre traitements respectivement. Avec la densité de peuplement la plus élevée le rendement était notamment plus élevé qu'avec tous les autres modes de traitement, mais le taux de conversion était nettement inférieur. Les écarts entre rendements nets et taux de conversion des deux traitements avec ou sans granulés etaient insignifiants. Le nombre moyen de juvéniles produits avec les quatre traitements était de 38 383, 99 146, 149 188 et 222 942 par ha pour les quatre modes de traitement respectivement. Le nombre de jeunes produit par les deux traitements appliqués aux bassins peuplés de 200 tilapias ne présentait guère de différence, mais la moyenne globale indiquait que la forme d'alimentation non-granulée est plus favorable à la survie et à la production des alevins.

Efectos de la cría a alta densidad y forma de alimento en la reproducción y rendimiento de *Tilapia aurea*

Extracto

Se cultivó *Tilapia aurea* durante 114 días en estanques de hormigón de 2,7 × 7,3 × 0,76 m (0,002 ha). Se utilizaron las siguientes concentraciones de *T. aurea*: 400 por estanque, alimentadas con piensos granulados; 200 por estanque, con piensos granulados; 200 por estanque, con piensos no granulados de la misma composición; y 100 por estanque con piensos granulados. Se alimentó a los peces diariamente, durante 6 días a la semana, en proporciones que variaron del 5 al 2% de su peso corporal.

Se tomaron muestras de los peces a intervalos de 4 semanas, para reajustar las cantidades de alimentos. Se llenaron todos los estanques con agua de pozo, aireándolos con un ventilador de 5 hp. Sólo se añadió agua para sustituir las pérdidas debidas a evaporación y filtraciones.

El rendimiento medio neto y la conversión de alimentos fueron, respectivamente, en los cuatro tratamientos: 17 307 kg/ha y 1,56; 12 151 kg/ha y 1,14; 10 561 kg/ha y 1,27; y 9 998 kg/ha y 0,92. Con la densidad más elevada, el rendimiento fue notablemente mayor que en los demás ensayos, pero la conversión de alimentos fue notablemente peor. La diferencia de rendimiento neto y conversión de alimentos en los dos ensayos con piensos granulados y no granulados no fué significativa. El promedio de formas juveniles obtenidas en los cuatro ensayos fue, respectivamente, 38 383, 99 146, 149 188 y 222 942 por ha. El número de formas juveniles conseguido en los dos ensayos de 200 tilapia/estanque no mostró diferencia significativa, pero la media general de los ensayos reveló que el empleo de alimentos no granulados resulta mejor para la supervivencia y la producción de alevines.

1 Introduction

The culture potentials of the tilapias (Cichlidae) have not been fully realized, mainly because of inadequate systems of population control (Hickling, 1962). *Tilapia aurea* accepts a variety of feeds, and makes efficient gains in ponds supplemented with agricultural by-products (Bayne, Dunseth and Garcia-Ramirios, 1976; Garcia-Ramirios and Bayne, 1974). Limited data are available on growth of *T. aurea* in cages and ponds when fed high quality pelleted fish feeds (Pagan, 1975). This report describes studies on high density culture of *T. aurea* in aerated concrete ponds and fed a formulated fish feed either in pelleted or non-pelleted form.

2 Materials and methods

2.1 *Experimental ponds and treatments*

Twelve concrete ponds each measuring 2·74 × 7·31 × 0·76 m and containing 15·3 m^3 of water were used in the experiment. Each pond had a surface area of 0·002 ha. Approximately 15% of the surface area of all ponds was covered with water hyacinths, *Eichhornia crassipes*. The following four treatments with three stocking densities, each replicated three times, were used:

Treatment 1 400 tilapia/pelleted feed
Treatment 2 200 tilapia/pelleted feed
Treatment 3 200 tilapia/non-pelleted feed
Treatment 4 100 tilapia/pelleted feed.

Treatments 2 and 3 were identical with regard to stocking density but in the former the fish were fed pelleted feed and in the latter a powder form of the formulation. Treatments were applied in blocks without randomization since the contiguous ponds were uniform and environmental variations were considered negligible.

2.2 *Water supply*
The water used in this experiment came from deep wells. The water level was maintained at approximately 0·76 m, and water lost due to evaporation and leakage was replaced whenever necessary.

2.3 *Stocking of fish*
Fingerling *Tilapia aurea* with an average weight of 13·61 g were stocked 10 June 1974 at rates approximating 25·11, 13·08, and 6·54 fish/m^3.

2.4 *Feeding*
Fish were fed a maintenance diet between the stocking date and 17 June 1974, at which time a feeding programme of 5% of the body weight fed daily six days per week was initiated. On 16 July 1974, the daily feeding rate was changed to 3% body weight and on 16 August 1974 to 2% body weight. This rate was continued until the ponds were drained on 22 October 1974. Fish were sampled at 4-week intervals for adjustment of feed allowance. The feed formulation in all treatments was Auburn 4, containing 35% protein. Treatments 1, 3 and 4 received sinking pellets and Treatment 2 received a powder form of the same formulation.

2.5 *Aeration*
All replications were aerated, beginning 10 July 1974, by a Sutobuilt Rotary Positive Blower, Model 3H powered by a 5 hp Westinghouse electric motor and rated to supply approximately 0·35 m^3 per minute. The 12 concrete ponds received approximately 1/3 of the blower output. It was not possible to determine the precise rate of air flow per pond since the same blower supplied air to a number of experimental units.

3 Results and discussion

3.1 *Yields and feed conversion*
Net yields and feed conversions resulting from all experimental treatments are presented in Table I. Treatment 1 (400 fish) produced the equivalent of 17 307 kg/ha, significantly greater ($P < 0·05$) than the other three treatments. There were no significant ($P < 0·05$) differences among the three treatments with lower densities, although the mean yield of Treatment 2 (200 fish) was 21% greater than Treatment 4 (100 fish).

Feed conversion efficiency was poorest (1·56) in Treatment 1 with the highest stocking density, where dissolved oxygen dropped to 0·4 ppm on 10 July. Supplemental aeration was provided and a reduction in feeding rates from 5% body weight to 3% body weight was effected. Feeding rate in other treatments was reduced accordingly. The relatively poor conversion, compared to 1·27, 1·14, and 0·92 for the treatments with lower denisities, was probably due to the deterioration in water quality.

Harvestable-sized fish (greater than 13 cm) comprised 98·8% of the yield in Treatment 1, compensating in large part for the inefficient feed conversion. In the other treatments, harvestable-sized fish were 93·2% (Treatment 2), 91·9% (Treatment 3), and 80·6% (Treatment 4). Decreasing proportion of harvestable fish was concomitant with decreasing food quotient (increasing feed conversion efficiency). The more efficient feed conversions may be attributed to better water quality, since feeding rates for Treatments 2, 3 and 4 were significantly lower than those for Treatment 1. A further possible explanation is that the lowered standing crop of fish in the former three treatments had more natural food to ingest along with the supplemental Auburn 4 (35% protein), thus better balancing their diets.

3.2 *Pelleted versus non-pelleted feed*
It has been demonstrated (Swingle, 1968) that there is significant benefit to feed conversion for catfish and carp if the feedstuff is pelleted. Large yields of tilapia have been reported from South Africa (Hickling, 1962) when only mill floor sweepings of finely ground grains were added to ponds, but there have been no documented studies on the value of pelleting feeds for tilapia. Table I shows comparative results for Treatment 2 (sinking pellet) and Treatment 3 (powdered form of the same feed formulation). Mean yield and feed conversion were about 10% better in Treatment 2 than in Treatment 3, but statistically there was no difference ($P < 0·05$) in either parameter.

This finding is of practical significance to those who wish to culture *T. aurea* and who are considering the acquisition of a pelleting machine on the supposition that pelleting feedstuffs is necessary for efficient utilization of food.

3.3 *Reproduction*
Reproductive success for *T. aurea* at the three stock population densities is summarized in Table I. An inverse relationship was evident between the stock density and the number of young produced. As the stock increased from approximately 2 pairs/m^2 to 10 pairs/m^2 in the concrete ponds, the average number of young produced per pair decreased from 9·02 to 0·39. There were significant differences ($P < 0·05$) among these means according to stock density. However, there was no significant difference ($P < 0·05$) between Treatment 2 (200 fish, pelleted feed) and Treatment 3 (200 fish, powdered feed). Even so, the

TABLE I
MEAN NET YIELDS, FEED CONVERSION AND REPRODUCTIVE SUCCESS OF *Tilapia aurea* IN 0·002 HA CONCRETE PONDS AT STOCK DENSITIES OF 100, 200 AND 400 PER POND

Treatment		*Net yields*		*Feed Conversion*	*Reproduction (No. of young)*	
No. fish/pond	*Type of feed*	*kg/pond*	*kg/ha*		*per female*	*per ha*
400	pelleted	35·1	17 307	1·56	0·39	38 383
200	pelleted	24·6	12 151	1·14	2·00	99 146
200	non-pelleted	21·5	10 581	1·27	3·02	149 188
100	pelleted	20·3	9 998	0·92	9·02	222 942

treatment means indicated that the non-pelleted form of feed was more conducive to survival and production of young.

4 Summary and conclusions

It is concluded from this study that *T. aurea* may be cultured at very high densities in concrete ponds if aeration is provided to compensate for the increasing oxygen demand due to the accumulation of organic matter resulting from high rates of feeding. Further, there seems no economic value in providing pelleted feed for *T. aurea*, which can utilize very small particles of prepared feed quite efficiently.

Finally, *T. aurea* reproduction can practically be eliminated by increasing stock density to the equivalent of 197 680/ha, at which level growth of the stock proceeds at a satisfactory rate.

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Elevage de Truite en Eau de Mer Dans le Fier d'Ars, Ile de Ré (France)

J. Masse

Résumé

Un essai d'élevage intensif de truites (*Salmo gairdneri*) en eau de mer a été tenté dans le cadre du développement de l'aquaculture dans l'Ile de Ré.

Si l'on ne dépend pour la circulation de l'eau que de l'effet de marée, seul l'élevage semi-intensif de truite associée à d'autres espèces sera possible. En vue d'une production plus intensive et à une plus grande échelle, le pompage de l'eau devient indispensable.

Trout culture in sea water in the Fier d'Ars, Island of Ré (France)

Abstract

Intensive raising of trout (*Salmo gairdneri*) in sea water on a trial basis was started as part of the programme for development of aquaculture in the Ile de Ré.

If only tidal movements have to be depended upon for water circulation, only raising of trout along with other species on a semi-intensive scale will be possible. If more intensive large-scale production is to be carried out, pumping will be necessary.

Cultivo de truchas en agua de mar en el Fier d'Ars, Ile de Ré (Francia)

Extracto

Como parte de los trabajos de desarrollo de la acuicultura se ha realizado en Ile de Ré un ensayo de cría intensiva de truchas (*Salmo gairdneri*) en aguas marinas.

Si se tuviese que depender únicamente de la circulación del agua, sólo sería posible la cría de trucha conjuntamente con otras especies en una escala semi-intensiva. Para lograr una producción en gran escala será necesario instalar estaciones de bombeo.

1 Introduction

Le Fier d'Ars est une baie très abritée, communiquant avec la mer par un étroit goulet (Fig. 1). Les conditions géographiques favorables, ainsi que l'ensoleillement important, ont favorisé l'exploitation de salines qui, à l'heure actuelle, sont en forte régression, en raison du caractère artisanal de cette activité, concurrencée par les grosses entreprises mécanisées de la Méditerranée. Les marais salants couvrent une surface d'environ 1 100 ha, dont 170 seulement sont en production. Une partie des marais désaffectés a été reconvertie en pâturage (150 ha). Excepté une centaine d'hectares envasés, près de 800 ha restent donc inutilisés.

Le circuit hydraulique dans les marais salants se résume ainsi: l'eau retenue, au moment des grandes marées, dans des réservoirs endigués (vasières) est ensuite acheminée par

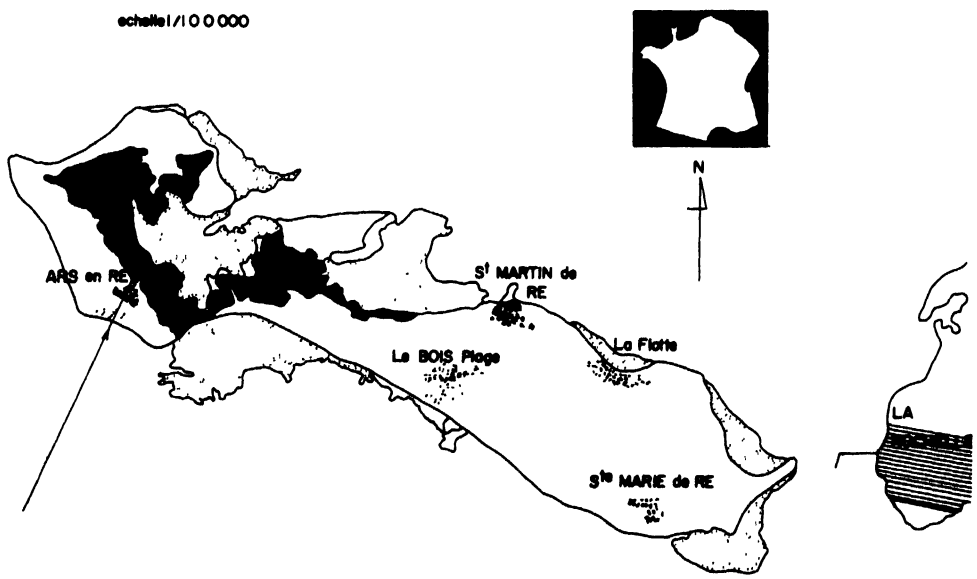


Fig 1. Carte de situation

un circuit compliqué, qui permet à l'eau de se réchauffer, vers les "oeillets" ou se produit la cristallisation du sel. Ces oeillets séparés par des talus de quelques centimètres de haut sont groupés par ensembles d'une surface de quelques hectares. Cette infrastructure hydraulique ne demande, pour être adaptée à l'aquaculture que des modifications réduites.

Le plan d'aménagement a donc été modelé sur le terrain en place, c'est-à-dire: (*i*) l'élevage intensif (poissons, crustacés, coquillages) dans les marais salants proprement dit; (*ii*) l'élevage semi-intensif de poissons ou élevages de coquillages suspendus dans les réservoirs.

Les premiers essais effectués en 1975 ont porté sur le premier point, de façon à évaluer les possibilités d'élevage intensif dans le cas d'une alimentation en eau uniquement par le jeu de la marée.

2 Aménagements et fonctionnement hydraulique

2.1 *Installations*

Elles comprennent:

(*i*) Deux réservoirs couvrant une superficie de 2·5 ha (16 000 + 9 000 m^2) communiquant par une buse de 30 cm de diamètre. L'entrée d'eau dans ces réservoirs se fait par un moine de 0,80 m de large communiquant avec le chenal. Le fond de ces bassins est situé à la côte variant entre 0,50 et 0,60 m ngf[1].

(*ii*) Deux couloirs d'élevage longs de 180 m, alimentés à partir de la réserve par une buse de 30 cm de diamètre. Ces bassins, larges de 2 m à la base et 5 m au sommet ont été construits en terre. Les ouvrages d'entrée et de sortie en maçonnerie permettent de régler le niveau d'eau.

Cette forme allongée a été choisie pour plusieurs raisons:

(*a*) Un essai antérieur, pratiqué dans un bassin rectangulaire (40 × 20 m) a montré que, pour une densité d'élevage compatible avec le débit disponible, les truites trop dispersées ne se regroupaient pas lors du nourrissage;

(*b*) Etant donné la largeur de ce bassin, le courant s'établissait au centre; par contre les bassins étroits facilitent l'auto-nettoyage;

(*c*) Les manipulations nécessaires (tris et prises d'échantillons) sont pratiquement impossibles dans un grand bassin.

Ces deux couloirs sont divisés par des grilles qui délimitent six bassins de 60 m. Les bassins sont situés le long d'un réservoir de 8 500 m^3 qui sert d'exutoire. En effet, le chenal d'évacuation n'étant pas refait, le canal d'amenée est utilisé à marée descendante pour rejeter l'eau emmagasinée à marée haute. Le fond de ce réservoir étant à + 0,70 m ngf une fosse a été creusée pour permettre l'assèchement des bassins si besoin est.

2.2 *Fonctionnement hydraulique*

L'alimentation en eau de la réserve se fait par le jeu des marées. Le schéma (Fig. 2) montre les hauteurs atteintes pendant une période de 3 mois, en fonction des coéfficients. Une coupe schématique des bassins y figure, permettant de déterminer pour quelles valeurs du coéfficient de marée l'alimentation gravitaire sera déficiente. En fait, cette évaluation n'est qu'approximative, car la hauteur de l'eau est également fonction des conditions météorologiques (vent). On notera également qu'on ne peut élever le niveau dans les réservoirs au-delà de la cote + 1,50 m ngf pour éviter le batillement.

En tenant compte des pertes de charge dans les buses (4 cm en tout pour un débit de 300 m^3/h), il faut maintenir l'eau dans les réservoirs à la cote + 1,10 m ngf pour assurer un débit minimum de 300 m^3/ha. La baisse de niveau dans les réservoirs est de 1,2 cm par heure, soit pour la durée d'une marée environ 15 cm. Le flot doit donc remplir la réserve à la cote 1,25 m ngf, ce qui est réalisé pour tous les coéfficients supérieurs à 80. Pour les coéfficients inférieurs à 45, l'alimentation devra être assurée par pompage: entre ces valeurs, la solution mixte doit être retenue, en fonction des hauteurs d'eau réelles. Selon les données obtenues, on peut prévoir un fonctionnement de la pompe à mi-temps pendant cette période.

L'acclimatation progressive a pu être réalisée en

[1] ngf = nivellement général de la France

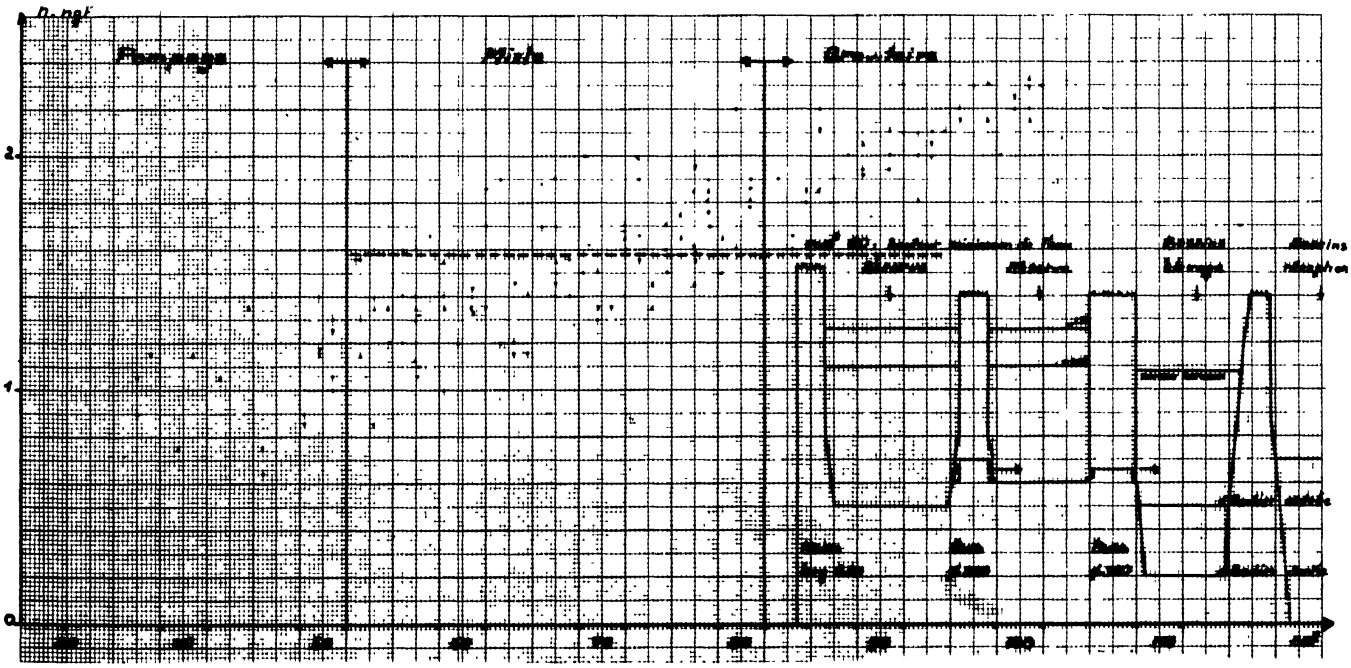


Fig 2. Hauteur de l'eau aux étales de pleine mer 'Prise de la clef des moulins' du 29 octobre 1973 janvier 1974

pompant une eau saumâtre dans un chenal voisin. La pompe utilisée (130 m^3/h) rejetait l'eau en tête d'un bassin de 60 m. Le mélange avec l'eau de mer était obtenu en ouvrant progressivement le circuit normal d'alimentation.

3 Elevage

3.1 *Mise en place de l'essai*

Un premier lot (200 kg) constitué d'individus nés pendant l'hiver 1972–73 a été mis dans de l'eau à salinité faible (18‰) le 4 décembre. Le passage à l'eau de mer (32‰) s'est effectué en une semaine. Parallèlement, un autre lot provenant de la même population a été placé en eau douce; le passage en eau de mer a été obtenu par une augmentation progressive du taux de salinité durant 15 jours.

Le lot suivant a été divisé en deux parties; les essais ont débuté: (*i*) le 10 décembre (350 kg); le passage à l'eau de mer a duré une semaine; (*ii*) le 18 décembre (650 kg); le passage à l'eau de mer a duré 2 jours.

Le lot a ensuite été regroupé, puis réparti également dans deux bassins. D'autre part, un petit lot a été mis à part, à l'entrée des bassins, et nourri avec un aliment non saumonisant.

3.2 *Conditions d'élevage*

Le débit admis dans les bassins a varié entre 200 m^3/h et 300 m^3/h selon les hauteurs atteintes par la marée. Les températures ont été enregistrées en continu. D'une manière générale les minima interviennent vers 12 h et les maxima vers 19 h.

Les températures sont restées comprises entre 9°C et 13°C pendant tout le mois de décembre. Ces conditions ont été favorables à l'élevage. Il n'est pas exclu que par temps froid la croissance subisse un retard, l'alimentation s'interrompant à des températures de l'eau inférieures à 8°C.

Le taux d'oxygène à l'entrée des bassins est toujours resté voisin de la saturation quelque soit l'heure de la mesure (9–11 ppm suivant la température). Pour un débit de 350 m^3/h, le taux d'oxygène, mesuré à la sortie des bassins, variait entre 7,6 et 7,9 ppm, pour une valeur à l'entrée de 9,2 ppm, soit une chute de 1,5 ppm environ; la charge lors des mesures est évaluée à 1 400 kg.

En admettant un taux d'oxygène minimum de 6 ppm, on peut grossièrement évaluer la capacité de ces installations à 3 000 kg dans les conditions données (débit 350 m^3/h— taux d'oxygène initial 9,2 ppm). Il est vraisemblable que le réchauffement de l'eau au printemps provoquera directement une baisse du taux de saturation et indirectement une consommation d'oxygène par les algues dans les réservoirs, ce qui contribuera à diminuer la quantité d'oxygène disponible et obligera par conséquent soit à augmenter le débit, ce qui impose une installation de pompage plus importante en période de morte eau, soit à diminuer la charge.

Ce réchauffement devient par ailleurs critique pendant la saison chaude. Des mesures faites pendant l'été 1974 dans les réservoirs ont montré que dès le mois de juin les températures atteignaient 23°C. Les maxima du mois d'août se situaient à 26°C. Il paraît donc impossible de poursuivre l'élevage pendant l'été dans ces bassins.

Le pH est resté constamment compris entre 7,7 et 8,0 durant l'expérience.

3.3 *Résultats*

(*i*) Lot No. 1.

Ce lot, composé de truites de deux ans, est très hétérogène: poids extrêmes de 60 et 190 g pour un poids moyen de 124,5 g.

Lors de la mise à l'eau, la salinité était de 18‰. Ce chiffre est monté les jours suivants de façon régulière, pour atteindre 32‰ le 12 décembre. Les mortalités enregistrées ont été relativement élevées (5,8%). Excepté le premier jour où la mortalité a uniquement affecté de petites truites, toute la mortalité enregistrée a été le fait de mâles matures. Par contre, il faut noter que sur les individus de même origine, adaptés progressivement de l'eau douce à l'eau de mer lors de l'essai effectué sur la Seudre, aucune mortalité n'a été observée du 18 novembre au 3 décembre.

Ce lot a été nourri avec un aliment contenant des pigments caroténoïdes (canthaxanthine) à partir du 6 décembre, la ration journalière représentant 1,2 à 1,8% du poids vif par jour. Le tableau ci-après rassemble les résultats obtenus.

Les échantillons prélevés le 29 décembre ont montré, du point de vue saumonisation, une pigmentation irrégulière. Tous les individus étaient colorés, la gamme très large allant du rose pâle au saumon clair. Le 15 janvier par contre, on peut considérer que l'ensemble de la population, sauf exception, a acquis une coloration "saumon" nette et uniforme.

(*ii*) Lot No. 2

Ce lot est composé de truites de l'année. La mise à l'eau s'est effectuée en deux fois: 350 kg le 11 décembre et 650 kg le 18 décembre, les échantillons prélevés ont montré des distributions identiques. La population est plus homogène que dans le premier lot et le poids moyen est supérieur (140 g). Les poids extrêmes sont 100 g et 195 g. Sur la première partie du lot, on a effectué un passage progressif à l'eau de mer. La salinité initiale était de 26‰. La salinité de l'eau de mer (33‰) a été atteinte régulièrement en huit jours sans qu'on ait eu à noter de mortalité notable.

Pour la deuxième partie du lot, le passage à la salinité maximale n'a duré que deux jours, mais aucune perte n'a été enregistrée.

Du 18 décembre 1974 au 15 janvier 1975, chaque lot a reçu 206 kg d'aliments.

Les échantillons prélevés le 15 janvier n'ont pas montré de différence significative de croissance; la distribution est identique et le poids moyen très voisin, soit: (*i*) 173,9 g et un coefficient de conversion égal à 1,70 pour la première partie du lot; (*ii*) 175,7 g et un coefficient de conversion égal à 1,62 pour la deuxième partie du lot.

Date	*Nombre des échantillons*	*Poids moyen (g)*	*Croissance journalière en % pour la période considérée*	*Poids global (kg)*	*Aliment distribué (kg)*	*Coefficient de conversion*
4/12	60	124,5	—	189,60	—	—
29/12	60	152,3	0,81	230,00	76	1,83
15/1	50	184,2	0,86	279,00	88	1,80

On peut rapprocher ces chiffres de celui obtenu sur les truites âgées de deux ans pour lesquelles le coefficient de conversion était de 1,83. Il semble bien que les poissons du premier lot soient de moins bons utilisateurs de l'aliment. Bien qu'il ne soit guère possible de tirer de conclusions générales sur la vitesse de croissance après 25 jours d'expérience, les données obtenues sur le deuxième lot peuvent être utilisées dans un premier temps comme base de calcul, soit un gain de poids de 34,8 g en 25 jours (ou 1% par jour) avec un coéfficient de conversion voisin de 1,7. Ce chiffre est une moyenne pour des truites d'un poids initial moyen car la croissance des individus les plus gros est beaucoup plus rapide.

Quant à la saumonisation, on ne peut que constater une coloration encore légère. Tous les sujets sont cependant pigmentés, alors qu'un échantillon prélevé le 29 décembre (11 jours d'élevage) présentait des individus de teinte généralement blanche.

4 Conclusions

Du point de vue fonctionnement, les installations utilisées sont très pratiques, tant du point de vue alimentation des truites que manipulation et surveillance des poissons. Deux remarques cependant sont à formuler: d'une part, la bri (argile gris bleu, dans laquelle les bassins sont creusés) forme au contact de l'eau une pellicule limoneuse qui est mise en suspension lors des mouvements des poissons et en particulier lors du nourrissage; l'eau se trouble très rapidement et peut favoriser la perte d'une partie de l'aliment, ce qui peut justifier le coéfficient de transformation relativement élevé.

D'autre part, l'alimentation gravitaire par le jeu des marées a pu être réalisée grâce à une réserve d'eau importante. Quoique ces réservoirs puissent être utilisés, soit pour des élevages extensifs de poissons, soit pour la conchyliculture, il n'est guère possible d'envisager une extension de l'élevage de la truite en intensif sans pompage. La solution la plus satisfaisante dans le cas d'un développement de cette activité sera certainement la création de réserves collectives alimentées par pompage, la distribution de l'eau étant assurés par gravité en aval.

Le passage de l'eau douce à l'eau de mer n'a pas présenté ici de problème pour les truites âgées de moins d'un an, que ce soit à une salinité réduite (23‰) ou à une salinité normale (33‰) et pour des poids compris entre 90 et 200 g. Par contre, une mortalité de 5,8% portant uniquement sur les mâles matures a été observée sur le lot de poissons âgés de deux ans, malgré la salinité réduite (23‰).

Il faut cependant être prudent dans ces conditions car des essais de passages directs effectués par ailleurs ont provoqué des mortalités importantes de poissons de même taille. Il y a donc un problème à approfondir, vraisemblablement sur les plans physiologique et génétique, quant aux phénomènes liés à l'adaptation de la truite à l'eau de mer. Enfin, on peut rapporter ici les résultats obtenus sur une autre station de Charente-Maritime, où l'augmentation progressive de salinité de 0 à 32‰ n'a causé aucune mortalité, que ce soit chez des poissons âgés de deux ans de même provenance que sur l'Ile-de-Ré, ou chez des truites de poids moyen égal à 90 g.

La saumonisation des poissons demande, pour être assurée d'une coloration homogène, l'apport de saumonisant pendant une durée minimum de 45 jours; les observations effectuées après 14 jours montrent des colorations variant du blanc au rose pâle; après 25 jours, les poissons sont colorés mais d'une manière irrégulière, quelques individus présentant une pigmentation acceptable, les autres se situant à tous les stades intermédiaires; aucune coloration de la chair n'est apparue sur le lot nourri avec un aliment normal.

Du point de vue croissance, les chiffres obtenus sont moyens; le taux de croissance mensuel de 30% obtenu sur un lot est satisfaisant, mais le coéfficient de conversion (1,7) est encore élevé. Ceci est peut-être dû au phénomène de turbidité relaté précédemment, peut-être à un défaut de pratique du pisciculteur. Il serait également intéressant de rechercher au niveau de la formulation de l'aliment si les critères retenus en eau douce sont transposables à l'eau de mer.

L'Elevage des Poissons en Eau de Mer: Nouveaux Résultats Français en Matière de Recherche et de Développement

M. Girin et Y. Harache

Résumé

Les auteurs font le point des travaux entrepris en France, depuis 1969, sous l'égide du CNEXO, pour favoriser le développement d'élevage de poissons en eau de mer.

Les poissons strictement marins relèvent encore du seul domaine de la recherche. Malgré quelques résultats interessants au plan de la croissance, les travaux sur la daurade dorée (*Sparus auratus*) et le turbot (*Scophthalmus maximus*) sont encore freinés par des difficultes mal surmontées dans l'élevage larvaire Par contre, un succès récent ouvre d'intéressantes perspectives pour la sole (*Solea solea*) tandis que le bar (*Dicentrarchus labrax*), paraît techniquement prêt à passer au stade des essais de développement.

Les poissons amphibiotiques ont déjà donne lieu à des essais de production commerciale, avec des résultats variables. Si l'élevage de l'anguille n'a, pour l'instant, pas abouti, plus de 100 tonnes de truites et de saumons ont pu être commercialises. Le marché se présente favorablement, mais il reste encore un certain nombre de problèmes, tant scientifiques que techniques, à résoudre avant d'espérer atteindre des productions comparables à celles de la Norvège ou des Etats-Unis d'Amérique.

Fish breeding in sea water: new results obtained in France with respect to research and development

Abstract

The authors sum up the work carried out in France since 1969 under the auspices of CNEXO to encourage the development of sea-water fish breeding.

Culture of fish which are strictly marine still belongs only to the research sector. In spite of some interesting results from the point of view of growth, work on gilthead bream (*Sparus auratus*) and turbot (*Scophthalmus maximus*) is still hampered by difficulties which are not easily overcome in the culture of larvae. On the other hand, recent successes open interesting prospects for sole (*Solea solea*), while culture of sea bass (*Dicentrarchus labrax*) seems technically ready to pass to the stage of development trials.

Commercial production tests have already been made on euryhaline fish with varying results. While eel (*Anguilla anguilla*) culture has not yet proved successful, it has been possible to place more than 100 tons of trout (*Salmo gairdneri*) and coho salmon (*Oncorhynchus kisutch*) on the

market. Market prospects are good, but a number of scientific and technical problems still have to be solved before yields comparable to those of Norway and the United States can be expected.

Cultivo de peces en agua de mar: nuevos resultados obtenidos en Francia relacionados con el campo de la investigación y el desarrollo
Extracto
Los autores presentan una reseña de los trabajos realizados en Francia desde 1969, bajo la égida del CNEXO, para promover el cultivo de peces en aguas marinas.

La cría de peces estrictamente marinos pertenece aún al campo de la investigación. A pesar de algunos resultados interesantes desde el punto de vista del crecimiento, los trabajos sobre la dorada (*Sparus auratus*) y el rodaballo (*Scophthalmus maximus*) se ven aún frenados por algunas dificultades de cría de larvas que no son fáciles de solucionar. En cambio, el éxito obtenido recientemente abre interesantes perspectivas para el lenguado (*Solea solea*), mientras por lo que se refiere a la lubina (*Dicentrarchus labrax*) todo parece estar técnicamente dispuesto para pasar a la fase de ensayos de fomento del cultivo.

Con los peces anfibióticos se han hecho ya ensayos de producción comercial, con diversos resultados. Aunque por el momento la cría de anguilas (*Anguilla anguilla*) no ha tenido éxito, se han podido comercializar, en cambio, más de 100 toneladas de truchas (*Salmo gairdneri*) y salmones (*Oncorhynchus kisutch*). El mercado ofrece condiciones favorables, pero quedan aún por resolver varios problemas, tanto científicos como técnicos, antes de poder lograr producciones comparables a las de Noruega o los Estados Unidos.

1 Introduction

Le développement de nouvelles techniques d'aquaculture marine dans un pays d'Europe occidentale tel que la France impose, au moins au départ, le choix d'espèces nobles, de haute valeur commerciale, pour lesquelles la pêche nationale ne suffit pas à couvrir la demande du marché. Les prix de détail atteints permettent d'espérer aboutir assez vite à des productions rentables, dont le succès pourra éventuellement alimenter la poursuite de la recherche vers des espèces moins nobles.

Encore faut-il que l'on puisse disposer des juvéniles en quantités suffisantes. La capture dans la nature est en général exclue au moins au niveau d'une exploitation importante. Cela impose soit le choix d'animaux pour lesquels des expériences nationales ou étrangères aient montré de longue date la fiabilité des techniques de production en masse de juvéniles, soit le développement d'une recherche originale dans ce domaine.

D'autre part, les 4 000 km de côtes françaises, réparties entre la Manche, l'Océan Atlantique, et la Mer Méditerranée, offrent une importante variété de conditions d'élevage possibles. Les températures moyennes de surface, en mer ouverte, varient en moyenne de 8° à 19°C en Atlantique, et de 10° à 22°C en Méditerranée, entre l'hiver et l'été. En estuaires, ou dans les lagunes côtières, ces limites peuvent être dépassées, dans un sens ou dans l'autre, de 8° à 10°C. La variété géographique des côtes offre aussi bien des possibilités d'élevage en cages, dans des baies protégées ou dans des estuaires, qu'en bassins à terre, ou en lagunes littorales.

Ces divers éléments, et le souci d'exploiter au mieux les connaissances disponibles, ont conduit depuis 1969 le Centre National pour l'Exploitation des Océans (CNEXO) à promouvoir et encourager des travaux sur diverses espèces de poissons susceptibles d'être élevés en eau saumâtre ou marine: daurade dorée (*Sparus auratus*), turbot (*Scophthalmus maximus*), sole (*Solea solea*), bar (*Dicentrarchus labrax*), anguille (*Anguilla anguilla*), truite (*Salmo gairdneri*) et saumons (*Salmo salar, Oncorhynchus kisutch*).

Des progrès substantiels ont été réalisés, qui se traduisent, sur le plan de la recherche, par plus de 30 publications scientifiques originales, et sur le plan du développement par plus de cent tonnes de production. Certains éléments de l'effort entrepris ont été décrits antérieurement, soit dans des revues plus générales que celle-ci (Laubier, 1974; Danioux *et al.*, 1975), soit dans des documents plus spécialisés (Girin, 1976; Harache et Novotny, 1976). La présente contribution est donc plus particulièrement consacrée à présenter l'évolution générale des travaux, et les nouveaux résultats obtenus ces deux dernières années.

2 Elevage de poissons en eau de mer

2.1 *Le turbot* (*Scophthalmus maximus*)

Le turbot est un poisson marin qui peut dépasser 10 kg, abondant en Mer du Nord, en Atlantique jusqu'aux côtes marocaines, et présent en Méditerranée. C'est un poisson plat, côtier, mais que ne fréquente guère les profondeurs inférieures à 10 m. Il ne fait l'objet d'aucune forme d'élevage traditionnel. Pourtant, les premièrs tentatives d'élevage sont très anciennes (Malard, 1899). Elles furent abandonnées pendant un demi siècle, puis reprirent à la fin des années soixante, en Grande-Bretagne (Jones, 1972) puis en France.

2.1.1 *Reproduction.* Dans les expériences françaises, les oeufs ont été obtenus d'abord par pression abdominale de géniteurs pêchés en période de reproduction (1971), puis captifs (1972–73). Depuis 1974, à la suite de la mise en service de bassins rectangulaires de 45 m^3 à fond de sable (1,6 m de profondeur d'eau), la ponte et la fécondation se font naturellement. Sur le plan quantitatif, l'approvisionnement en oeufs ne pose pas de problème, dans la limite du demi-million par semaine pendant les 2,5 mois de la saison de ponte (mai à juillet). Les taux de fécondation obtenus sont cependant encore très variables d'une ponte à l'autre. L'emploi de sperme conservé dans l'azote liquide ne semble pas altérer le taux d'éclosion ou la capacité de survie des larves (Billard et Dupont, communication personnelle).

2.1.2 *Elevage et alimentation.* L'élevage larvaire pose des problèmes. La métamorphose ne s'achève qu'après 8 à 10 semaines d'élevage, et si quelques 600 juvéniles de 2,5 g (environ 4 mois à 18°C) ont pu être conditionnés à un aliment composé en 1974, 10 seulement l'ont été en 1975. Le meilleur taux de survie à ce stade (6%) obtenu dans une expérience de 1973, n'a jamais été reproduit. Les phases les plus délicates de l'élevage semblent se situer entre 10 et 15 jours, au moment de l'introduction de nauplii d'*Artemia* dans le régime, et entre 40 et 60 jours, au moment de l'abandon des proies vivantes (à 18°C).

L'absence de concentrations de juvéniles dans la nature a limité le développement de nouvelles expériences de nutrition. Cependant, un test portant sur une centaine d'animaux nés en mai 1974 a permis de mettre en évidence des besoins particuliers en acides gras polyinsaturés (Luquet et Gatesoupe, communication personnelle), tandis que des expériences sur de jeunes animaux mettaient en évidence un optimum de croissance pour des journées de 12 h environ (Lahaye et Deniel, 1976). Une expérience de grossissement en bassin, réalisée sur quelques 400 poissons de la même génération, avec un aliment composé présenté sous forme humide, a permis d'obtenir au bout de 20 mois, dans les conditions de température naturelles de la Bretagne, un

poids moyen de 350 g (Metailler, communication personnelle).

2.1.3 *Résultats.* Pour ce que l'on en sait aujourd'hui, le turbot apparaît comme une espèce bien adaptée à l'élevage intensif, en cages ou en bassins: il vient chercher sa nourriture en surface, tolère de fortes charges, s'accommode bien de l'absence de sable, et paraît au total très robuste. Mais les difficultés rencontrées au niveau de l'élevage larvaire bloquent pour l'instant tout développement des programmes le concernant.

2.2 *La daurade dorée* (*Sparus auratus*)
La daurade dorée est un poisson marin côtier, fréquent en lagunes, présent, en zone tempérée, dans les deux hémisphères, et courant sur les côtes européennes, en Atlantique comme en Méditerranée. En Méditerranée, et particulièrement en Italie, elle fait souvent l'objet d'une aquaculture traditionnelle extensive, basée sur la capture des juvéniles en estuaires, et leur grossissement sans apport de nourriture dans des lagunes aménagées.

2.2.1 *Reproduction.* Les premiers essais de fécondation artificielle de cette espèce remontent aux environs de 1925, en Nouvelle Zélande (Morrisson Cassie, 1956), mais les premières tentatives réelles d'élevage larvaire n'ont commencé qu'à la fin des années soixante, en France et en Italie. En France, les recherches, après avoir connu une plus grande extension, sont maintenant limitées à la Station de Biologie Marine de Sète, l'ecloserie expérimentale de Maguelone, et une société privée, l'Association des Compagnons de Maguelone.

La ponte naturelle en captivité n'a pas encore été obtenue, et l'obtention des oeufs fécondés repose toujours sur l'induction hormonale de la ponte (gonadotrophine chorionique). Mais la constitution de stocks de géniteurs en 1974 a libéré des captures pendant la période de reproduction (entre novembre et janvier). Après induction de la ponte, le fécondation naturelle, moins traumatisante, tend à remplacer la fécondation artificielle, sauf besoin expérimental précis. Dans ce dernier cadre, des expériences de conservation de sperme dans de l'azote liquide ont permis d'obtenir des fécondations et des larves viables (Billard et Dupont, communication personnelle).

2.2.2 *Elevage et alimentation.* Depuis 1973, l'élevage larvaire n'a progressé ni sur le plan des taux de survie, ni sur celui des quantités de juvéniles produits (moins de 100 en 1974 et 1975). Dans le même temps, les expériences de nutrition, après avoir abouti à la réalisation d'un aliment industriel, ont été interrompues.

Par contre, l'emploi de juvéniles capturés dans la nature a permis de réaliser sur la côte méditerranéenne des expériences de grossissement assez prometteuses (Association des Compagnons de Maguelone); 10 000 juvéniles en 1974, et 7 000 en 1975, capturés fin mai, aux environs de 3 g, ont été élevés dans trois expériences différentes, à des densités de 2 à 4 individus par m^2, en association avec des crevettes pénaeides. Au mois de décembre, les poids moyens variaient de 60 à 85 g, pour des animaux nourris avec un granulé industriel, et libres de le compléter à leur guise avec une partie du crabe broyé et des moules offerts aux crevettes.

2.2.3 *Résultats.* Ces résultats présentent la production d'animaux de taille commerciale (200 à 300 g) en deux étés comme techniquement possible sur nos côtes. La méthode d'élevage choisie n'est cependant peut-être pas la plus adéquate. Il semble y avoir une certaine compétition entre la crevette et le poisson, et la daurade supporte mal les basses températures de l'hivernage en étang. D'où le développement de projets d'élevage en cages ou en bassins, qui viennent de débuter à l'écloserie expérimentale de Maguelone (Febvre, communication personnelle).

2.3 *La sole* (*Solea solea*)
La sole est un poisson marin côtier de répartition géographique voisine de celle du turbot, qui affectionne les fonds de faible profondeur, et se rencontre souvent en lagunes. C'est très généralement le poisson plat le plus apprécié dans tous les pays riverains. La demande du marché impose des importations abondantes des pays de la Mer du Nord. Elle ne fait l'objet d'aucune forme d'élevage traditionnel. Comme pour le turbot, après des tentatives très anciennes (Fabre-Domergue et Bietrix, 1905), puis un demi-siècle d'oubli, des essais d'élevage larvaire ont repris d'abord en Allemagne (Fluchter, 1965) et en Grande-Bretagne (Shelbourne, 1968), puis en France.

2.3.1 *Reproduction.* Dans les expériences françaises, les oeufs fécondés sont obtenus par ponte naturelle en captivité, dans un bassin circulaire de 20 m^3, à fond de sable (80 cm de profondeur d'eau). Les quantités récoltées n'ont pas encore dépassé quelques dizaines de milliers d'oeufs par saison. Des tentatives d'induction de la ponte par injection de gonadotrophine chorionique n'ont pas donné de résultats nets, tandis que l'injection de progestagène a permis le déclenchement d'une ponte en 1974 (Billard, communication personnelle).

L'élevage larvaire est relativement facile, et des taux de survie de 60 à 80% après la métamorphose (3 semaines à 18°C) sont courants.

2.3.2 *Elevage et alimentation.* Jusqu'en 1975, le verrou de l'élevage se situait au niveau du conditionnement des juvéniles à un aliment inerte. La jeune sole se nourrit sur le fond, lentement, et de préférence la nuit, caractères qui rendent le contrôle de son alimentation très difficile. En cas d'emploi d'un aliment mal apprécié, les animaux peuvent se maintenir en vie plusieurs semaines, sinon plusieurs mois, avec une croissance plus ou moins nulle, jusqu'à l'apparition d'une mortalité souvent massive. Ils semblent alors avoir atteint un point de non-retour, refusant même d'accepter de nouveau des proies vivantes. D'où la réputation faite à la sole d'être un poisson à croissance lente, et difficile à maintenir en élevage.

La mise au point d'un schéma de passage progressif de la proie vivante à un aliment composé présenté sous forme de granulé sec a permis de fournir une solution. La méthode consiste à remplacer, aux environs de 50 mg (30 à 40 jours à 18°C) les *Artemia* vivantes employées par des *Artemia* congelées, auxquelles sont progressivement substitués des aliments composés. Ces aliments contiennent des appétants naturels (*Artemia*, Polychètes, krill) en proportions décroissantes, pour aboutir aux environs de 2 g (90 à 100 jours à 18°C) à un animal se nourrissant convenablement d'un aliment composé normal. Le taux de survie à ce stade peut dépasser 15% (Metailler et Girin, 1976).

Sur le plan de la nutrition, les exigences en protéines (40 à 50%) et en lipides (10 à 12%) dans la ration semblent assez voisines de celles des autres espèces étudiées. Pour le grossissement, sauf à très faible charge, la présence d'un fond de sable semble indispensable. La suppression du sable pendant quelques semaines est possible, mais des tentatives plus longues ont toujours entraîné jusqu'à présent l'apparition de mortalités liées à des nécroses avec infections bactériennes, qui commencent généralement par la queue et la bordure des nageoires. Dans un tel cas, la thérapeutique la plus efficace semble être un retour rapide sur fond de sable. L'emploi de cette technique a permis d'obtenir un poids moyen de 11 g à l'âge de 6 mois (18°C) pour un lot de 400 animaux, pratiquement sans mortalité (Metailler, communication personnelle). L'utilisation de granulés classiques se traduisait cependant par d'importantes pertes de nourriture. Un enrobage du granulé avec une protéine végétale, assurant une bonne stabilité à l'eau, a récemment permis de réduire ces pertes, sans affecter la croissance (Gatesoupe et Metailler, communication personnelle). Une photopériode fixée aux environs de 12 h de jour semble favoriser la croissance (Lahaye et Deniel, 1976). Un test à petite échelle (400 poissons) de libération d'animaux de 500 mg encore habitués à une nourriture vivante, dans un bassin à fond sablo-vaseux de 500 m^2, a permis d'obtenir au bout de 4 mois une survie de 15%, avec une croissance similaire à celle observée en laboratoire.

2.3.3 *Résultats.* De telles caractéristiques conduisent à concevoir le grossissement de l'espèce, soit en conditions extensive, sans apport de nourriture, dans des lagunes côtières aménagés, soit en conditions semi-intensives avec des méthodes, et dans des structures semblables à celles qui sont employées pour les crevettes pénaeides. Mais aucun essai de ce genre n'a encore pu être tenté.

2.4 *Le bar* (*Dicentrarchus labrax*)

Le bar est un poisson marin côtier, courant en Atlantique, de la France au Maroc, et dans tout le bassin méditerranéen. Comme la daurade, il est fréquent en lagunes, et les jeunes se rencontrent souvent en grandes quantités dans les estuaires. Il fait l'objet du même type d'aquaculture traditionnelle que la daurade.

Les tentatives d'élevage larvaire de cette espèce n'ont cependant débuté qu'à la fin des années soixante, en France et en Italie. En France, les travaux, qui se sont rapidement développés, impliquent les stations marines de Marseille et Sète, le Centre Océanologique de Bretagne et l'écloserie expérimentale de Maguelone.

2.4.1 *Reproduction.* L'obtention des oeufs fécondés, qui était considérée, jusqu'en 1974, comme le principal facteur limitant de l'élevage, ne pose plus de problème particulier sur le plan de la quantité, dans la limite du million d'oeufs par semaine, pendant les 4 à 8 semaines de la saison de ponte (entre janvier et avril, suivant les lieux). Chaque équipe pratique le méthode la mieux adaptée à ses objectifs et aux possibilités locales: injections hormonales (gonadotrophine chorionique) de géniteurs fraîchement pêchés, ou maintenus en captivité, avec ou sans fécondation artificielle, ou ponte et fécondation naturelles en captivité.

Les travaux sur la ponte s'orientent maintenant vers la conservation des gamètes, le décalage de la saison de ponte et le contrôle de la qualité des oeufs obtenus. Des tests de congélation et décongélation de sperme ont été faits, sans qu'il soit possible de réaliser des essais de fécondation (Billard et Dupont, communication personnelle). La ponte naturelle en captivité a été avancée d'un mois en 1975, et de deux mois en 1976, sur un lot expérimental, par décalage progressif de la photopériode et de la thermopériode. Les pontes naturelles en capitivité font apparaître une réduction progressive de la taille moyenne des oeufs pondus par un lot de géniteurs donné au fur et à mesure de l'avancement de sa saison de ponte, et des différences pouvant aller du simple au double en volume entre les tailles moyennes des oeufs pondus par différents lots. Ces différences de taille semblent avoir une influence non négligeable sur la survie des larves: des taux de survie à un mois variant de 10 à 50% ont été enregistrés dans des conditions d'élevage similaires, pour des oeufs de différentes provenances.



Fig 1. Bacs d'expérimentation sur l'élevage larvaire du bar, de la sole, et du turbot, au Centre Océanologique de Bretagne

2.4.2 *Elevage et alimentation.* Trois années de progrès rapides dans la technique de l'élevage larvaire en 'bloom' contrôlé avaient permis de parvenir à une production de l'ordre de 120 000 animaux d'une centaine de milligrammes (deux mois à 18°C) en 1973. Des difficultés rencontrées dans la maîtrise de cette technique à grande échelle ont provoqué alors la recherche de nouvelles techniques d'élevage, dans des volumes ne dépassant pas quelques m^3, mais à des densités plus élevées, et en faisant largement appel à l'emploi d'aliments inertes. En 1975, ces travaux ont permis de mettre à la disposition des expériences de nutrition et de grossissement quelques 30 000 animaux de 500 mg à 1 g (deux mois et demi à trois mois à 18°C), se nourrissant bien d'aliment composé (granulé sec). Des schémas de conditionnement au granulé ont été décrits (Girin, Barahona-Fernandes et Roux, 1975; Barahona-Fernandes et Girin, 1976). Les charges employées en début d'élevage tournent couramment autour de 50 larves/l, les proies vivantes peuvent être abandonnées dès 50 mg (un mois à 18°C) et les taux de survie peuvent dépasser 35% pour le poisson de 1 g (trois mois environ à 18°C). De ces résultats, et des expériences d'élevage larvaire avec de l'aliment composé réalisées par Barnabe (1975 et communication personnelle), il est à prévoir une évolution rapide vers la suppression plus ou moins totale des proies vivantes.

En nutrition, l'étude des besoins alimentaires de poissons de quelques centaines de milligrammes à quelques grammes a montré que des différences très légères dans les formules

des aliments peuvent jouer de façon considérable, non seulement sur la croissance, mais aussi sur la survie (Barahona-Fernandes, Girin et Metailler, 1976; Metailler, communication personnelle).

Pour les poissons plus gros, les travaux s'orientent vers la recherche de sources protéiques de remplacement susceptibles de réduire les coûts de production (levures et protéines végétales). Plusieurs aliments industriels sont disponibles sur le marché.

2.4.3 *Résultats.* Les expériences de grossissement sur le terrain n'en sont encore qu'aux balbutiements. Les expériences avec des animaux pêchés dans la nature ont été abandonnées, faute d'un approvisionnement suffisant, tandis que celles avec des animaux nés en écloserie sont encore rares. Des essais lancés avec des animaux nés au printemps 1975 ont cependant permis d'obtenir des poids moyens de 15 à 20 g à fin de l'été, en Atlantique comme en Méditerranée, en bassins à terre et en cages. Mais aucune expérience n'a encore été menée jusqu'à la production d'animaux commercialisables.

Compte tenu du blocage à peu près total de la croissance des animaux en dessous de 10°C, l'élevage se conçoit plus logiquement en Méditerranée qu'en Atlantique, sauf sélection d'animaux particulièrement performants. Mais l'emploi de cages en baies protégées, évitant les fortes baisses de températures hivernales des étangs, pourrait permettre l'implantation d'élevages au moins sur une partie des côtes atlantiques. La meilleure chance de développement de cette espèce se trouve cependant peut-être ailleurs sa bonne tolérance aux fortes charges et aux basses salinités la désigne comme un sujet particulièrement bien adapté aux élevages intensifs dans des eaux de refroidissement de centrales électriques implantées sur le littoral. Aucun essai de ce type n'a encore été envisagé en France, mais une expérience est déjà en cours en la Republique Fédérale d'Allemagne (Tiews, communication personnelle).

2.5 *L'anguille* (*Anguilla anguilla*)

Les civelles sont très abondantes dans certains estuaires français ou elles font l'objet d'une pêche traditionnelle, destinée principalement à l'exportation, soit pour la consommation (Europe du sud), soit pour l'élevage (Japon).

Plusieurs entreprises françaises ont tenté d'adapter, sur les côtes atlantiques et méditerranéennes, les techniques d'élevage japonaises aux possibilités françaises, sans recherche originale préalable. A l'heure actuelle, la plupart de ces tentatives ont été abandonnées. Il semble qu'une certaine sous-estimation des problèmes techniques ait empêché d'atteindre le seuil de rentabilité. En particulier, la pêche des animaux en hiver, au moment où le marché est le plus intéressant, s'est avérée très difficile dans les conditions climatiques naturelles.

2.6 *La truite arc-en-ciel* (*Salmo gairdneri*)

L'élevage de la truite arc-en-ciel en eau de mer a débuté en 1970, à l'initiative d'un patron-pêcheur disposant d'un étang à marée endigué sur la côte nord de Bretagne. Cette opération a bénéficié de l'aide scientifique et financière du CNEXO depuis 1971.

Le niveau de l'étang permet le renouvellement de l'eau par gravité à chaque marée, et un ruisseau d'eau douce permet de contrôler la salinité du plan d'eau. Les températures varient de 4 à 25°C au cours de l'année, ce qui a conduit à limiter l'élevage à la période octobre-juin et à produire ainsi de la truite portion (220–250 g).

Des truitelles de 30 à 100 g âgées de 10 à 11 mois sont adaptées à l'eau de mer à partir du mois d'octobre. La salinité, située aux environs de 10‰, à l'origine est progressivement augmentée jusqu'à 30–33‰ au cours de l'hiver. Les conditions atmosphériques peuvent cependant entraîner des variations sensibles au cours de la période d'élevage. La nourriture est constituée d'un aliment mixte composé de faux poisson, de déchets de sciage de morue surgelée et de farine de poisson. La chair des truites est colorée par addition à la nourriture d'un pigment caroténoïde (cantaxanthine) et des essais de finition à l'aide de krill sont en cours. La période de commercialisation s'étend de décembre à juin.

L'élevage dispose de différentes structures de production comprenant 4 bassins en terre, 3 bassins carrés de type suédois (100 m^2) et des cages flottantes en filet situées dans l'étang.

En 1971, quelques centaines de kg étaient commercialisés à un prix supérieur à celui de la truite d'eau douce. La production passait ensuite de 4,5 tonnes en 1972 à 30 tonnes en 1975. En 1973, une pollution causée par des herbicides détruisait la totalité du cheptel (25 tonnes) empêchant cette exploitation familiale d'atteindre le seuil de rentabilité.

D'autres élevages utilisant des techniques similaires se créaient à partir de 1973, sur la côte atlantique et en Méditerranée, permettant d'atteindre une production de près de 100 tonnes en 1975.

Des essais de grossissement jusqu'à une taille supérieure (de l'ordre de 1,5 à 2 kg), effectués à petite échelle, en cages flottantes, ont donné des résultats de croissance satisfaisants (passage de 160 g à 1 kg en 6 mois). Les hautes températures estivales empêcheront probablement les éleveurs disposant d'étangs à marée de prolonger la période d'élevage jusqu'à cette taille, mais la production en cages flottantes dans certaines zones appropriées devrait permettre de développer l'élevage de grosses truites de mer. Le marché de ce nouveau produit est encore mal connu. Il ne semble cependant pas très favorable en France et en Europe.

2.7 *Le saumon coho* (*Oncorhynchus kisutch*)

Le CNEXO a débuté un programme de recherches sur l'élevage du saumon en 1971. Si les rivières de Bretagne produisaient 4 500 tonnes de saumon avant la Révolution, les captures actuelles ne dépassent pas 10 à 15 tonnes par an et les pêches groënlandaises (2 500 à 3 000 tonnes) sont considérées comme dangereuses pour la survie de l'espèce. Les causes principales de cette désastreuse diminution sont le manque de gestion des rivières, la sur-exploitation, une législation inadaptée, la dégradation de l'environnement et l'absence presque totale de stations de production de smolts de repeuplement. Dans ces conditions, il était impossible d'obtenir des oeufs provenant des stocks sauvages, et le manque de structure d'élevage appropriée conduisait à louer les installations de production de truites arc-en-ciel d'un pisciculteur breton. Le saumon coho (*Oncorhynchus kisutch*), plus facile à produire en eau douce que le saumon atlantique (*Salmo salar*), était choisi pour les premiers essais.

Un premier lot de 60 000 oeufs embryonnés de saumon coho fut importé des Etats-Unis en décembre 1971;

200 000 suivirent fin 1972, 400 000 en 1973, et à partir de 1974 les importations se stabilisèrent à 1 million d'oeufs par an. Parallèlement, des oeufs de saumon atlantique étaient importés chaque année d'Ecosse pour procéder à des essais de production de smolts.

Deux techniques d'élevage étaient envisagées à la même époque: l'utilisation des étangs à marée fréquents sur les côtes bretonnes, et le développement de productions en cages flottantes dans des baies ou estuaires abrités. A cet effet, une société pilote, la SODAB (Société pour le Développement de l'Aquaculture en Bretagne) fut créée en 1973, avec le CNEXO comme actionnaire majoritaire. Deux autres stations expérimentales utilisant des cages flottantes en mer étaient créées en 1974 et 1975 avec des co-opératives de pêcheurs.

2.7.1 *Expériences d'élevage.* La SODAB utilise une pisciculture traditionnelle, autrefois spécialisée dans la production de truites portion, pour élever les jeunes saumons jusqu'au stade de smolt. Un ancien moulin à marée, situé sur l'estuaire du Jaudy sur la côte nord de Bretagne sert pour l'élevage jusqu'à la taille commerciale. L'étang, d'une superficie de 6 000 m^2, garde une profondeur moyenne de 4 m, quelle que soit la marée. Le renouvellement de l'eau est assuré par deux élévateurs de 600 m^3 h fonctionnant 9 à 11 heures sur 24, et une pompe de circulation, débitant 3 600 m^3 h crée un courant dans l'étang. Aux plus hautes marées, l'eau est renouvelée naturellement par gravité. Les saumons sont élevés dans 16 cages octogonales de type norvégien, d'un volume de 193 à 230 m^3. En 1975, une digue submersible fut construite en aval de l'étang, créant un nouveau bassin de 2 000 m^2 permettant de disposer de 12 cages supplémentaires. La digue, submergée à toutes les hautes mers, retient une hauteur d'eau de 4 m à marée basse. Une étude écologique des deux plans d'eau est en cours pour tenter de déterminer les limites de sécurité pour une production intensive.



2. Cages flottantes octogonales de la SODAB dans l'étang à marée du Carpont, ayant servi a produire 20 tonnes de saumon en 1975

Une autre station expérimentale, de taille plus réduite, a été créée en 1974 dans une baie protégée de la rade de Brest. Un radeau en tubes métalliques soudés comportant 4 cages de 60 m^3 et calculé pour résister à des vagues de 1,50 m a été mis en place en juin 1974. Cette opération est conduite par une co-opérative de pêcheurs, la COMAT (Co-opérative Maritime Aquacole du Tinduff), le CNEXO assurant le financement de l'opération. Après une année de test des cages, un nouveau radeau constitué de cinq cages de 220 m^3 a été mis en exploitation à l'automne 1975. Il doit permettre de produire environ 20 tonnes de saumon et de truites, pour évaluer les possibilités économiques de ce type d'élevage. Au total, la capacité totale de production de la station devrait être de 30 à 35 tonnes annuellement, sans modification des structures.



Fig 3. Installations de grossissement de saumon en eau de mer de la COMAT, dans la rade de Brest. Capacité: 30 tonnes environ

Une troisième expérience, menée par un groupement de pêcheurs de la côte nord de Bretagne et financée par le CNEXO est en cours depuis 1975 dans l'estuaire du Jaudy. Elle dispose de deux cages octogonales de type norvégien.

2.7.1.1 En eau douce: Les deux premières années furent consacrées à l'étude de l'élevage en eau douce, des expériences d'adaptation à l'eau de mer étant menées en laboratoire au Centre Océanologique de Bretagne. La survie après un an d'élevage fut de 50% la première année, et de 85 et 96% pour les deux lots de l'année suivante. En 1975, une pollution détruisit 400 000 parrs.

Les oeufs sont incubés et les larves sont élevées à une température de 10°C, sur eau de source en circuit fermé, puis sur eau de rivière à partir d'avril. Il est possible d'obtenir la smoltification lors de la première année d'élevage, alors que cette espèce smoltifie à l'âge de 18 mois dans les conditions naturelles de la côte pacifique des Etats-Unis.

La première année, seulement 20% de la population montrait des signes de smoltification en juin-juillet (15–20 g) et octobre (35 g). Les deux lots obtenus en 1972 montraient des résultats différents, l'un ne produisant que des smolts d'un an, l'autre en fournissant 50% de l'âge 0. Cinquante pour cent de la population de la génération 1973 se smoltifiait en juillet 1974.

2.7.1.2 Passage à l'eau de mer: Les premiers poissons furent transférés directement en eau de mer dans l'étang à marée de la SODAB en décembre 1973 et janvier 1974, à un poids de 180 à 500 g (smolts de 1 et 2 ans). Les poissons, nourris avec un granulé sec du commerce montrèrent une croissance de 0,4 à 1,1% par jour de janvier à mars, selon les tailles et les différents groupes. La mortalité fut négligeable jusqu' à la commercialisation, intervenant de mai à juin, pour des poissons de 300 à 800 g. En 1974, 7,6 tonnes furent ainsi commercialisées sur le marché

parisien, au prix de F.F. 18–20/kg hors taxes, départ de la pisciculture, pour des poissons frais et entiers.

Des tentatives de transfert direct de smolts en eau de mer ont été effectuées de mai à juillet en 1974 et 1975, avec des jeunes saumons d'âge 0⁺ et 1⁺. Dans tous les cas, les mortalités au cours de l'été ont été considérables variant de 70 à 100% selon les sites d'élevage.

Les smolts d'âge 0 provenant de la ponte 1973 ont été transférés dans les cages en mer en juillet 1974, à un poids moyen de 26 g. Dans le meilleur des cas, le taux de survie fut de 22% à la fin de l'été, la moitié des survivants présentant cependant une excellente croissance, atteignant un poids moyen de 393 g fin décembre (accroissement journalier 1,1%), 735 g début avril 1975 et 1 373 g en octobre 1975. La deuxième moitié de la population eut une croissance faible associée à une régression à l'état de parr.

Les smolts d'âge 1⁺ de 70 g, après une mortalité de l'ordre de 70% pour le meilleur lot, ont également montré une croissance remarquable, atteignant les poids moyens de 525 g en décembre (accroissement journalier 1,1%) 1 050 g en avril 1975 et 1 590 g en octobre 1975. Peu de germes pathogènes furent isolés en dépit de symptômes externes inquiétants. *Aeromonas salmonicida* fut cependant cultivé à partir des smolts d'âge 1⁺ en juillet.

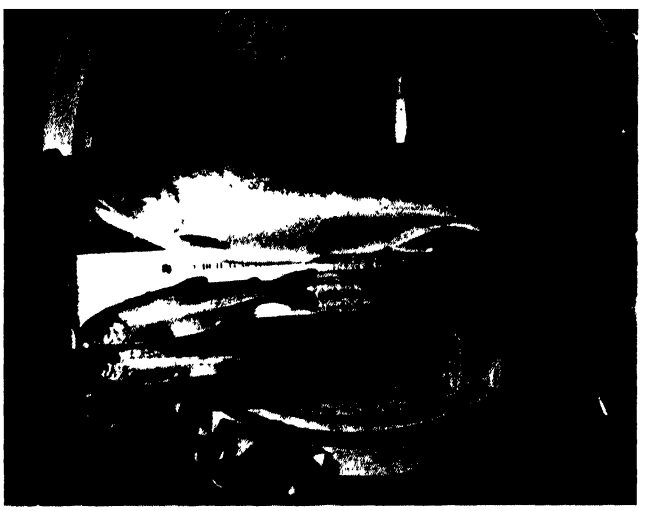


Fig 4. Croissance d'*Oncorhynchus kisutch* en cages flottantes: de 70 g à 700 g en 6 mois

En 1975, des conditions climatiques exceptionnelles entraînèrent des températures de surface de l'ordre de 20°C et le taux de survie fut encore plus faible. Des *Vibrio* apparentés à l'espèce *Vibrio anguillarum* furent isolés à plusieurs reprises pendant l'été.

2.7.2 *Résultats.* Actuellement, la majeure partie de la production française s'effectue en hiver, après adaptation à l'eau de mer en octobre et en novembre. Les smolts sont soit des poissons de l'année ayant un poids minimum de 70 g, soit des poissons ayant séjournés près de 2 ans en pisciculture et pesant 150 à 200 g. Les éleveurs utilisent soit un aliment mixte composé de poisson broyé et de farine, soit un aliment sec du commerce.

La commercialisation s'effectue de janvier à juin, selon les lots. En dépit d'une croissance inférieure à celle obtenue après adaptation au printemps, ce type de production reste très intéressant du fait du faible taux de mortalité, de l'ordre de 5%.

En 1975, la production totale fut de 25 tonnes environ, dont 22 commercialisées par la SODAB. En 1976, les nouvelles structures mises en place devraient permettre de produire 80 à 120 tonnes.

Les premiers saumons élevés en France ont atteint la maturité sexuelle en 1973, à l'âge de 2 ans, pour un poids variant de 300 g à 1 kg. Le taux de survie des oeufs à l'éclosion passait de 1% la première année, à 20% en 1974 pour des poissons conservés pendant toute leur vie en eau douce. Les alevins issus de ces oeufs se sont avérés très robustes et ont présenté une excellente croissance en eau douce, arrivant au même poids moyen en octobre (43 g) que les alevins issus d'oeufs d'importation malgré 6 semaines de retard au début de l'alimentation. Par contre, à l'heure actuelle, aucun succès notable n'a été obtenu avec les poissons élevés en eau de mer.

L'aquaculture du saumon coho semble appelée à se développer rapidement sur les côtes françaises et pouvoir atteindre une production de l'ordre de 500 tonnes vers 1980. Une adaptation plus précoce au printemps (mars-mai), l'amélioration des aliments utilisés et un contrôle plus efficace des épizooties devraient permettre d'effectuer dès 1977, deux productions annuelles et de commercialiser des produits frais, toute l'année. Parallèlement, l'élevage du saumon atlantique en eau douce a montré en 1975 des progrès intéressants et les premiers essais de production en eau de mer seront effectués dès 1976.

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Preliminary Observations Related to Culture of *Rhamdia hilarii*, a Brazilian Catfish

C. R. Machado and N. Castagnolli

Abstract

The Brazilian catfishes, *Rhamdia quelen* and *R. hilarii*, appear to offer potential as target species for aquaculture in spite of their relatively slow growth rates. They are omnivorous feeders readily adapting to artificial feeding; they are hardy and easy to handle; their flesh is tasty and almost boneless; and they have high fecundity. Studies on *R. hilarii* were undertaken to stimulate semi-intensive culture in the many small dams existing in Brazil through determination of rational rearing techniques, and establishing suitable techniques for breeding and distribution of fingerlings at low cost to the farmers.

Under experimental conditions, sexual maturation of *R. hilarii* peaked between October and February. Linear relationships were found for this species between total body length and weight, fecundity and total length, and fecundity and body weight. Fecundity varied from <20 000 eggs for females measuring up to 250 mm up to almost 180 000 eggs for females measuring 370 mm.

Spawning was induced in both males and females using doses of 0·5 and 1·0 IU/g of the synthetic hormone 'Pregnyl'. Fish generally spawned 14 hours after the first hormone application. High fertilization (70–80%) levels were recorded, but only 10–20% of the fry hatched out 26–30 hours after fertilization at a water temperature of 26°C.

The best growth of fingerlings was recorded in ponds fertilized with chicken manure and nitrogen and phosphorus fertilizers, compared with ponds fertilized with manure and an inorganic fertilizer. *R. hilarii* fed artificial pellet feeds with 20 and 28% crude protein content had a significant weight increase at the higher protein level, but showed no significant difference in length increase for the two feeds.

Observations préliminaires sur l'élevage du poisson-chat brésilien *Rhamdia hilarii*

Résumé

Les poissons-chats brésiliens *Rhamdia hilarii* et *R. quelen* semblent convenir particulièrement bien à l'aquaculture en dépit de leur taux de croissance relativement faible, du fait qu'ils sont omnivores et s'adaptent facilement au nourrissage artificiel, qu'ils sont robustes et faciles à manipuler; leur chair est savoureuse et n'a pratiquement pas d'arêtes, et ils sont très féconds. Des études ont été entreprises sur *R. hilarii* afin de stimuler l'élevage semi-intensif dans les nombreux petits barrage existant au Brésil en déterminant des techniques d'élevage rationnelles et en établissant des techniques destinées à faciliter la reproduction et la distribution d'alevins à bas prix aux éleveurs.

En conditions expérimentales, la maturation sexuelle de *R. hilarii* a atteint son point culminant entre octobre et février. On a déterminé une relation linéaire, pour cette espèce, entre longueur totale et poids, fécondité et longueur totale et fécondité et poids. La fécondité a varié entre <20 000 oeufs pour les femelles mesurant moins de 250 mm et de près de 180 000 oeufs pour les femelles de 370 mm.

La reproduction a été induite aussi bien chez les mâles que chez les femelles par des doses de 0,5 et de 1,0 UI/g d'hormones synthétiques 'Prégnyl'. Les poissons ont en général pondu 14 heures après la première application d'hormones. On a enregistré des niveaux élevés de fertilisation (70 à 80%) mais 10 à 20% seulement d'alevins sont éclos entre 26 et 30 heures après la fertilisation, dans l'eau à 26°C.

Les meilleures croissances d'alevins ont été enregistrées dans les étangs fertilisés á la fiente de poulet ou avec des engrais azotés et phosphorés, les résultats étant moins favorables dans les étangs fertilisés à la fiente et avec seulement un des engrais non organique. *R. hilarii* nourri de granulés contenant 20 et 28% de protéines brutes ont sensiblement amélioré leur poids à la teneur protéique la plus élevée, leur longueur étant pratiquement la même pour l'un et l'autre régime alimentaire.

Primeras observaciones sobre el cultivo del bagre brasileño *Rhamdia hilarii*

Extracto

A pesar de que su tasa de crecimiento es relativamente lento, los bagres brasileños *Rhamdia hilarii* y *R. quelen* parecen ofrecer buenas posibilidades para la acuicultura, dado que son omnívoros que se adaptan fácilmente a los piensos artificiales, son resistentes y fáciles de manipular, su carne es sabrosa y casi sin huesos, y son muy fecundos. Se han iniciado estudios sobre *R. hilarii* para estimular el cultivo semi-intensivo de esta especie en los numerosos pequeños embalses que existen en el Brasil, preparando técnicas racionales de cría y sistemas adecuados para la producción y distribución de jaramugos a bajo costo.

En condiciones experimentales, la maduración sexual de *R. hilarii* alcanzó el punto máximo entre octubre y febrero. Se ha observado una relación lineal entre la talla total y el peso, la fecundidad y la talla total, y la fecundidad y el peso corporal. La fecundidad varió de <20 000 huevos en hembras de hasta 250 mm a 180 000 huevos en hembras de 370 mm.

Para inducir el desove de las hembras y la eyaculación de esperma de los machos se han utilizado dosis de 0,5 y 1,0 UI/g de la hormona sintética 'Pregnyl'. La suelta de huevos o espermatozoos se produjo en general a las 14 horas de la primera aplicación de hormonas. Se registraron elevados indices de fertilización (70–80%), pero sólo se obtuvo un 10–20% de avivamientos a las 26–30 horas de la fertilización, con el agua a temperatura de 26°C.

Las mejores tasas de crecimiento de los jaramugos se registraron en estanques fertilizados con estiércol de aves de corral y fertilizantes nitrogenados y fosforados, que se compararon con otros fertilizados con estiércol y uno de los fertilizantes inorgánicos. Se alimentó a *R. hilarii* con piensos artificiales granulados con un 20 y un 28% de contenido en proteínas crudas, lográndose un importante aumento de peso con el pienso más rico en proteínas, pero no se observó ninguna diferencia significativa de longitud con ninguno de los dos piensos.

1 Introduction

Among Brazil's indigenous fish, the catfishes *Rhamdia quelen* and *R. hilarii* present characteristics that indicate their potential as target species for aquaculture.

Although *Rhamdia* species have relatively slow growth rates, efforts to culture them should be encouraged because they: (*i*) are omnivorous feeders and can adapt to artificial feeding; (*ii*) are hardy and easy to handle; (*iii*) have tasty and almost boneless flesh, and may attain a body weight of almost 3 kg; and (*iv*) have relatively high fecundity.

Their reproduction generally occurs in flooded areas during the rainy season from September to December. Spawning in both species is easily induced through hormone injection. In Brazil, Von Ihering and Azevedo (1936) have published notes concerning *R. quelen*. They successfully used hormone injections with hypophysial extract to induce breeding and described some phases of embryonic and larval development, but the species has not yet been considered for commercial or domestic fish farming.

This paper is concerned with *Rhamdia hilarii* (Fig. 1), which is found from the Prata to Amazon Basins.

The main reason for these studies was to stimulate semi-intensive culture of *R. hilarii* in the many small dams in Brazilian rural areas through determination of rearing techniques, and establishing techniques for breeding and distribution of fingerlings at low cost to farmers.



Fig 1. Rhamdia hilarii ripe female (March 1976) measuring 195 mm total length and weighing 235 g

2 Materials and methods

Fish were collected from small tributaries of the Mogi-Guaçu River (Parana-Urugai Basin in the central southern region of Brazil) with conical bamboo traps, 1·5–2·0 × 0·3–0·4 m, set on the bottom near the banks, with the mouths facing upstream. Captured fish were held in ponds

(9·0 × 5·0 × 1·2 m and 2·0 × 1·0 × 8·0 m) of the Fish Culture Section of the Faculdade de Medicina Veterinária e Agronomia de Jaboticabal.

In order to determine their food habits, maturation curve and fecundity throughout the year (1974–75), fish were measured, weighed and dissected. Spawning was successfully induced with two hormone injections of 'Pregnyl' (CGH) at a dosage of 0·5 and 1·0 IU/g of fish. Fish growth was observed under natural and artificial (pellet) feeding regimes.

For the first trial, 25 fingerlings were stocked in three earthen ponds (9·0 × 5·0 × 1·2 m) after fertilization as follows:

Pond 1—Chicken manure (500 kg/ha), nitrogen (50 kg/ha) in the form of ammonium sulphate, and phosphorus (20 kg/ha) in the form of superphosphate;

Pond 2—Chicken manure and nitrogen fertilization at the same levels as pond 1;

Pond 3—Chicken manure and phosphorus fertilization at the same levels as in pond 1.

The second experiment was conducted in the same ponds, each stocked with 10 marked fish. Two artificial pelleted feeds containing 20 and 28% crude protein were fed twice a day at 5–8% body weight.

Both experiments lasted for three months, and fish growth was determined at monthly intervals.

Fecundity determinations were made using Simpson's (1951) method. Ovaries were immersed in Gilson's fluid for 1–2 weeks and strongly shaken until the eggs were completely separated. The solution was drained through fine-mesh nylon and eggs separated with tweezers and dried for 20 minutes at room temperature. After weighing all eggs together, 0·5 g samples were counted, and total fecundity estimates made. Body weight/total length, fecundity/body weight, and fecundity/total length correlations were determined and regression curves plotted.

3 Results and discussion

3.1 *Gonado-somatic index and maturation curve*

From May 1974 to April 1975, samples of fish were collected monthly and after measuring and weighing, were sacrificed in order to study their gonadal development.

According to Godinho *et al* (1974) the gonado-somatic index (GSI) is expressed as the relationship (per cent) between the weight of the gonad and total body weight, and is calculated as follows;

$$\text{GSI} = \frac{100 \times \text{gonadal weight}}{\text{Total body weight}}$$

For these determinations 103 fish weighing 150–510 g and measuring 180–380 mm in total length were sacrificed as follows: May (1974)—5; June—8; July—7; August—5; September—12; October—10; November—10; December—10; January (1975)—10; February—8; March—9 and April—9.

The mean monthly GSI values for *Rhamdia hilarii* reared under experimental conditions are shown in Fig. 2. *R. hilarii* reached sexual maturation in August and spawning occurred from October to December. This period was followed by a decline in sexual maturation, and by April all fish were spent. Comparison of these results with those of Castagnolli (1974) for common carp (*Cyprinus carpio*) shows that carp in the same region begin 'ripening' earlier

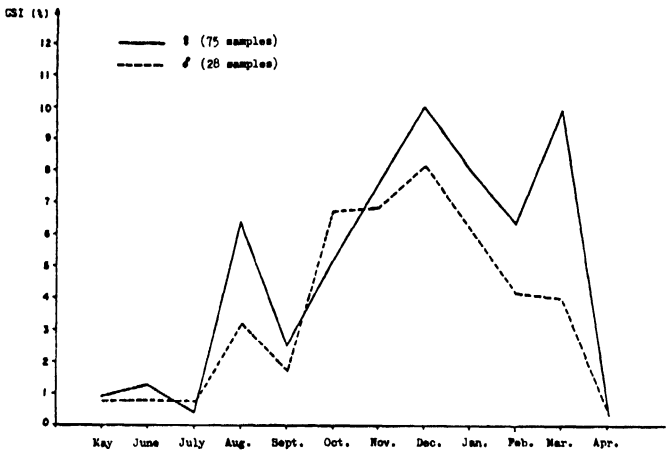


Fig 2. Maturation curve of *Rhamdia hilarii*

(from April/May), and reproduction begins in August and goes on to December.

Godinho *et al* (1974), studying the reproduction behaviour of another pimelodid fish, *Pimelodus maculatus*, observed the annual variation of GSI and the possible interaction of abiotic factors, such as water temperature, precipitation and water level fluctuation. *Pimelodus* reach sexual maturity in November, the spent stage from December to February, and are in the quiescent stage from March to September, according to Basile-Martins *et al* (1975).

3.2 *Estimation of fecundity*

For this purpose, 30 sexually ripening females of *Rhamdia hilarii* were sacrificed and their fecundity estimated as described. From these data the correlation between body weight and total length was first studied. A linear relation was found for these two parameters, which could be expressed by the regression equation:

$$Y = ax + b$$

In this equation Y = body weight (g), x = total length (mm) and the values of a and b constants estimated by the minimum squares methods were, respectively, 1·79 and −238·30 ($r = 0{\cdot}95$). These data enabled the estimation of an increment of 1·79 g for each mm growth in total length (Fig. 3).

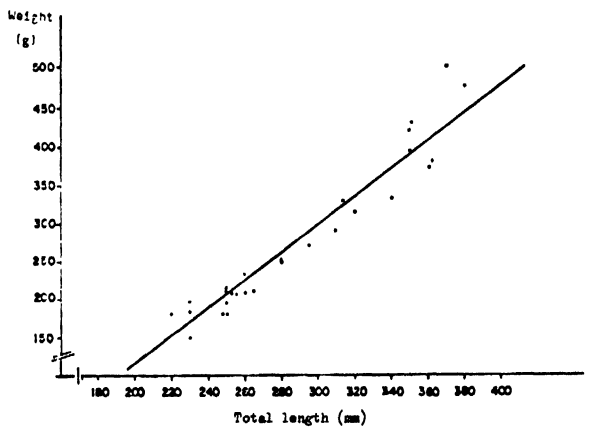


Fig 3. Body weight/total length relationship

A high and positive linear relationship was also observed between total length and fecundity ($r = 0{\cdot}88$) (Fig. 4) and for body weight and fecundity ($r = 0{\cdot}89$) of *R. hilarii* (Fig. 5). The values of the constants a and b in the regression

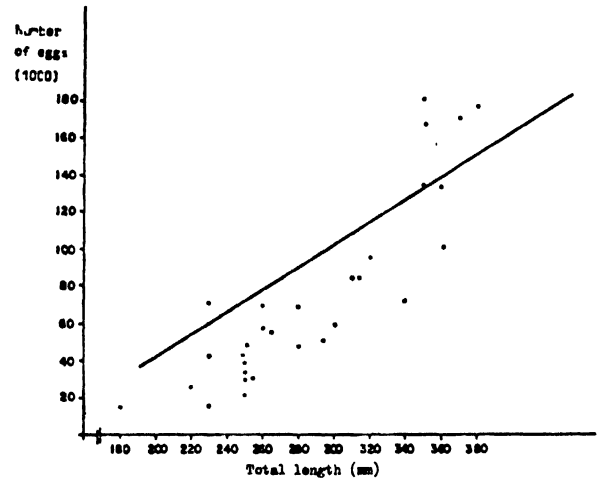


Fig 4. Absolute fecundity/total length relationship

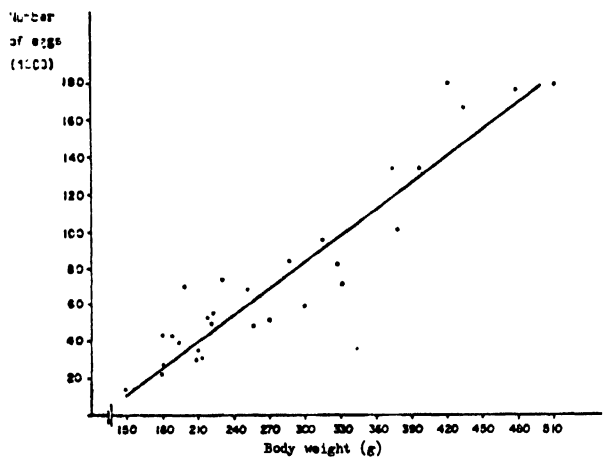


Fig 5. Absolute fecundity/body weight relationship

equation for total length versus fecundity were 860·20 and −73·84, respectively, which indicates an increment of 860 eggs for each mm of fish growth. Similarly, the constants *a* and *b* were calculated from the regression equation for body weight versus fecundity to be 463·11 and −55·58 respectively, which indicates an increment of 463 eggs for each gram increment in fish body weight.

3.3 *Induced spawning*

In November 1974 and December 1975, induced spawning was tried with 'Pregnyl', a CGH synthetic hormone. Doses applied to males and females were 0·5 and 1·0 IU/g of fish at 6–8 hour intervals. Generally, fish spawned with slight ventral pressure 14 hours after the first hormone application.

High fertilization levels (70–80%) were recorded but only a low percentage of fry (10–20%) hatched out 26–30 hours after fertilization at 25°C (Fig. 6).



Fig 6. Egg and newly hatched fry (0); 1-day (1) and 2-day (2) old fry

3.4 *Growth under natural and artificial (pellet) feeding regimes*

Initially, feeding habits were studied through observation of stomach and gut contents. Predominant food organisms were: small fishes, blue-green algae, chlorophyceae and diatomaceous algae, and slime and clay. In aquaria, *Rhamdia hilarii* were also observed feeding on artificial feed (pellets).

In further experiments to assess the growth of *R. hilarii* under different feeding regimes, earthen ponds 9·0 × 5·0 × 1·2 m with 4–5 l/min water flow were used.

3.4.1 *Natural feeding in fertilized ponds.* For this experiment, 25 *Rhamdia* fingerlings from one brood originating from induced spawning were stocked in three experimental ponds. The experiment began on 1 April 1975 and lasted for 90 days. The results are summarized in Table I.

The pond that received organic manure plus nitrogen (N) and phosphate (P) inorganic fertilizers gave the best increments in fish weight and length gains indicating the benefits of complete fertilization of ponds in rearing juvenile *R. hilarii.*

3.4.2 *Artificial (pellet) feeding.* For this trial, two ponds of the same sizes as the previous experiment were used, and each pond was stocked with ten marked fish. Pond 1 received pellet feed with 20% crude protein (Ration 1) and fish in the second pond were fed with Ration 2 containing 28% crude protein (Table II). Fish were fed twice a day at a rate of 5% of the body weight. The experiment began on 1 August 1975 and lasted for 90 days.

The two crude protein levels in rations were selected based on previous work on catfish feeding. Dupree and Sneed (1966), working with channel catfish fingerlings fed with rations containing 12–52% crude protein, observed linear response in growth rate up to the 35% level of crude

TABLE I
GROWTH OF *Rhamdia hilarii* IN FERTILIZED PONDS[1]

Fertilizers	*Mean body weight (g)*				*Net weight gain*	*Mean total length (mm)*				*Net length increase*
	Initial	*30 days*	*60 days*	*90 days*		*Initial*	*30 days*	*60 days*	*90 days*	
Organic manure plus N and P	9·2	33·6	43·3	64·5	55·3	93	143	152	169	76
Organic manure plus N	8·4	21·2	34·2	45·8	37·4	91	123	135	144	53
Organic manure plus P	9·2	14·6	33·8	39·2	30·0	97	129	135	142	45

[1] Mortality rate = 6%

protein in the food. Nail (1965) concluded that rations containing 25–34% crude protein did not provide significant differences in catfish growth. Simco and Cross (1966) tried rations with 20, 30, 40 and 50% crude protein content for catfish feeding and found that a ration containing 20% crude protein gave the worst results, while there was no significant difference between the other feeds (30–50% crude protein). Finally, Tiemeier and Deyoe (1973) found that good to excellent results were obtained by feeding channel catfish with a variety of rations containing 23·2–34·2% protein.

TABLE II
COMPOSITION OF PELLETED FEEDS

Ingredients	*Crude Protein* (%)	*Ration 1* (%)	*Ration 2* (%)
Corn bran	8	55	27
Meat meal	45	16	26
Soy meal	45	15	27
Rice bran	13	4	8
Wheat meal	13	9	11
Mineral mixture	—	1	1
Total		100	100

The results of these experiments are given in Tables III and IV, where it can be seen that the ration containing 28% protein provided better results. Differences were significant at the 95% confidence level for weight gain, but no statistically significant difference between the two feeds was observed in relation to fish length.

4 Conclusions

(*i*) *Rhamdia hilarii* is a good food fish with potential for cultivation. It is omnivorous, can adapt to artificial feeding, and has high fecundity.

(*ii*) Initial experiments have not, however, demonstrated rapid growth under intensive culture.

(*iii*) Under experimental conditions, sexual maturation occurred from October to March, indicating a long spawning period.

(*iv*) Fry hatch out within 26–30 hours after fertilization at a water temperature of 25°C.

(*v*) Fingerlings presented better growth in ponds fertilized with organic (chicken manure) plus nitrogen (N) and phosphorus (P) fertilizers than in organic manured ponds plus only N or plus only P fertilizers.

(*vi*) Pelleted feed containing 28% crude protein provided faster growth in weight ($P<0.05$) than feed with 20% crude protein content.

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TABLE III
GROWTH OF *Rhamdia hilarii* IN POND 1
(PELLET FEED WITH 20% CRUDE PROTEIN CONTENT)

Fish No.	*Weight (g)*				*Net weight gain*	*Total length (mm)*				*Net length increase*
	Initial	*30 days*	*60 days*	*90 days*		*Initial*	*30 days*	*60 days*	*90 days*	
1	183	200	212	227	44	267	280	289	300	33
2	105	122	133	146	41	227	230	238	256	29
3	153	170	179	187	34	240	245	252	268	28
4	140	152	180	193	53	280	288	295	300	20
5	149	154	162	171	22	200	230	240	260	60
6	167	171	180	188	21	215	225	250	165	40
7	120	144	152	162	42	180	193	210	222	42
8	105	130	147	159	54	170	188	205	212	42
9	95	94	109	115	20	160	177	185	200	40
10	65	76	100	111	46	145	160	171	182	37
Total	1 282	1 413	1 554	1 659	377	2 084	2 216	2 335	2 465	381
Average	128·2	141·3	155·4	165·9	37·7	208·4	221·6	233·5	246·5	38·1

TABLE IV
GROWTH OF *Rhamdia hilarii* IN POND 2
(PELLET FEED WITH 28% CRUDE PROTEIN CONTENT)

Fish No.	*Weight (g)*				*Net weight gain*	*Total length (mm)*				*Net length increase*
	Initial	*30 days*	*60 days*	*90 days*		*Initial*	*30 days*	*60 days*	*90 days*	
11	160	170	182	192	32	200	224	242	250	50
12	172	192	218	223	51	190	268	224	235	45
13	130	144	162	177	47	170	180	191	200	30
14	97	119	133	148	51	148	161	173	180	32
15	128	154	174	191	63	180	193	198	217	37
16	115	143	157	169	54	170	189	205	220	50
17	82	95	112	127	45	148	165	182	200	52
18	70	92	113	122	52	161	182	194	212	51
19	77	95	110	128	41	172	191	209	222	50
20	82	96	113	133	51	184	199	211	227	43
Total	1 113	1 300	1 474	1 600	487	1 723	1 892	2 029	2 163	440
Average	111·3	130·0	147·4	160·0	48·7	172·3	189·2	202·9	216·3	44·0

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Studies on the Culture of the Threadfin, *Polydactylus sexfilis*, in Hawaii[1]

Robert C. May

Abstract
A 2 year study of the aquacultural potential of *Polydactylus sexfilis* was carried out in Hawaii. Fish maintained in a suspended net enclosure displayed spontaneous spawning with a lunar rhythm over a 6 month spawning season. Larvae were reared from captive-spawned eggs to the juvenile stage. Juveniles and adults could be conditioned to feed on dried artificial rations, including floating pellets, and food conversion rates were favourable. Measurements of growth in small cages showed that marketable fish of 300 g could be produced from 9 g fry in 300 days at ambient temperatures in Hawaii. Growth rates could be increased by maintaining temperature and salinity within optimal ranges. These results indicate that this species has high potential for aquaculture in Hawaii, where it fetches a high market price. It is suggested that the culture of *Polydactylus sexfilis*, and perhaps other polynemid fishes, may also be feasible in other parts of the Indo-Pacific region.

Etudes sur l'élevage du barbur, *Polydactylus sexfilis*, aux Hawaii
Résumé
On a étudié pendant deux ans aux Hawaii les possibilités d'élever *Polydactylus sexfilis*. Des poissons, maintenus dans un enclos de filets suspendus, ont frayé spontanément suivant un rythme lunaire, au cours d'une période de reproduction de 6 mois. Les larves ont été élevées à partir d'œufs pendus en captivité, jusqu'au stade juvénile. Les juvéniles et les adultes ont pu être conditionnés à se nourrir de rations artificielles sèches y compris des granulés flottants; les taux de conversion alimentaire ont été satisfaisants. Il apparaît que l'on peut produire du poisson de taille commerciale (300 g) en 300 jours, à la température ambiante des Hawaii, à partir d'alevins de 9 g. On pourrait accroître les taux de croissance en maintenant la température et la salinité dans des limites optimales. Les possibilités d'élever cette espèce aux Hawaii, où le prix de vente est intéressant, semblent donc prometteuses. *Polydactylus sexfilis* et peut-être d'autres polynémidés, pourraient être cultivés dans d'autres parties de la région Indo-pacifique.

Estudios sobre el cultivo del barbudo, *Polydactylus sexfilis*, en Hawai
Extracto
En Hawai se han estudiado durante dos años las posibilidades del *Polydactylus sexfilis* para la acuicultura. En jaulas de red suspendidas los peces desovaron espontáneamente, con ritmo lunar, durante una temporada de desove de seis meses de duración. Se incubaron los huevos producidos por los peces en cautividad y las larvas se criaron hasta la fase juvenil. Se acostumbró a las formas juveniles y a los adultos a alimentarse con raciones secas, incluidos comprimidos flotantes, obteniéndose tasas favorables de conversión de los alimentos. Midiendo el crecimiento de los peces en jaulas pequeñas se observó que es posible obtener en 300 días, a temperatura ambiente, peces comercializables de 300 g a partir de alevines de 9 g. Puede aumentarse la tasa de crecimiento manteniendo la temperatura y la salinidad dentro de una escala óptima. Los resultados indican que esta especie ofrece grandes posibilidades para la acuicultura en Hawai, donde el precio de mercado de estos peces es elevado. Indican además que el cultivo de *Polydactylus sexfilis*, y quizás de otros polinémidos, podría ser factible en otras partes de la región del Indo-Pacífico.

1 Introduction

The family Polynemidae, or threadfins, which is distributed worldwide in warm seas, includes fishes esteemed for their quality as food. The Hawaii Institute of Marine Biology began investigating the threadfin or 'moi', *Polydactylus sexfilis*[2], as a potential culture organism in 1973 because of its high market value and the rapid growth rates which previous workers (Lowell, 1971; Kanayama and Morris, 1965) had found. The studies summarized below have revealed additional biological aspects of the species which indicate that it is well suited for culture. This work was carried out by a team which included G. S. Akiyama, D. Y. Hashimoto, R. C. May, T. R. Rao, M. T. Santerre and L. T. Watarai.

2 Spawning

Preliminary work in 1973 showed that *P. sexfilis* could be induced to spawn with injections of gonadotropic hormones. Subsequently it was found that mature fish maintained in a suspended net enclosure were spawning spontaneously; hormone injections were therefore not necessary. Water from the net was sampled continuously with an airlift pump to collect eggs when spawned and to study the pattern of spawning. In this way it was found that *P. sexfilis* spawned with a well defined lunar rhythm, always in proximity to the last quarter phase of the moon, and that spawning occurred over a 6 or 7 month period, from April or May to October (May, Akiyama and Santerre, MS). Furthermore, the fish spawned at roughly the same time each night, between 20.30 and 21.30 hours.

Only a small percentage of the eggs produced by spawners in the net enclosure was collected by the airlift pump, the vast majority being lost through the meshes of the net. It was found that fish transferred to a large tank (7·5 m^3) just before the predicted time of spawning would spawn at the same time as fish left undisturbed in the net enclosure, and in this way all eggs produced by the spawners could be collected.

3 Larval rearing

The spawning habits of *P. sexfilis* made it possible to collect extensive material for studies of embryonic and larval development. In a study of the influence of temperature and salinity on eggs and early larvae, Santerre (in preparation) determined that the optimum temperature at these early stages was 26°C and that slightly lowered salinities had no detrimental effect. Larvae obtained from the May 1974 spawning were reared in a 7·5 m^3 tank on a diet of rotifers (*Brachionus plicatilis*) and copepods (*Euterpina acutifrons*) in the presence of phytoplankton (*Chlorella* sp. and an unidentified euglenoid). The larvae were offered a diet of *Artemia* nauplii beginning on day 10. Juveniles were weaned onto chopped squid by day 44, after a short period on frozen adult *Artemia*. The mean temperature during the first 40 days of rearing was 24·9°C (range 23·7–26·6°C). A total of 1 360 newly hatched larvae were introduced into the tank, and 40 days after hatching 76 juvenile fish, or 5·6%, were still alive. The change from the larval to the

[1] Contribution No. 487, Hawaii Institute of Marine Biology.

[2] Some authors (e.g., Jordan, 1917–20; Kagwade, 1970) consider the genus *Polydactylus* synonomous with *Polynemus*. The author follows Myers (1936) and others in considering *Polydactylus* a distinct genus.

juvenile stage involved a gradual increase in pigmentation between days 30 and 40; there was no abrupt metamorphosis. An estimated 15 to 20% of the initial larvae were alive on day 20, the mortality between days 20 and 40 being attributed to lack of a suitable food for fish at the end of the larval stage.

4 Growout

4.1 *Artificial diets*

P. sexfilis is by nature a carnivore. It was therefore apparent at the outset of these experiments that in Hawaii, where no trash fish are available, economically viable culture of this species would hinge on the readiness of the fish to consume artificial diets. Results from the last two years have shown that *P. sexfilis* will readily consume dried, artificial diets, including both sinking and floating feeds. After suitable conditioning, these fish show an extremely vigorous feeding response to floating commercial trout chow, even though they are primarily bottom feeders by nature. A 21 day laboratory experiment showed that fish weighing approximately 100 g converted 13 to 18% of the trout chow (40% protein) to body weight tissue on a dry weight basis at an average temperature of 27·2°C. The 18% dry:dry conversion efficiency was equivalent to a dry:wet food conversion of 1·6, *ie*, it took 1·6 g of dry food to produce 1 g of live fish.

In order to overcome the high cost of imported commercial feeds, the Hawaii Institute of Marine Biology has tested dry feeds formulated in Hawaii from locally available ingredients. A standard diet has been designed, consisting of Hawaiian fish meal, soybean meal, high gluten wheat flour, soybean oil, cod-liver oil, and supplemental vitamins and minerals. So far, the maximum dry weight conversion efficiency on diets of this type has been 10·5% (dry:wet conversion, 2·7). As more is learned about the nutritional requirements of *P. sexfilis*, it is hoped that locally produced diets can be formulated which yield conversion efficiencies comparable to those now obtained with imported feeds. To reduce the cost of feeds still further, novel feed ingredients are also being tested, such as the high-protein legume, *Leucaena leucocephala*.

4.2 *Growth in cages*

Preliminary studies of cage culture were begun in July 1974. Juvenile *P. sexfilis* were collected in shallow water on windward Oahu, Hawaii, and placed in square cages of 13 mm ($\frac{1}{2}$ in) galvanized wire mesh (0·5 m^3 water volume) at a density of 50 fish/m^3 of water. The average weight of fish which were fed chopped squid *ad libitum* once each day, increased fourfold from 8·8 to 37 g during the first month, and increased from 37 to 74 g during the second month in captivity; water temperatures during these two months averaged 27·9°C with a range of 26·0°C to 29·9°C. Records from the cages during the second month allowed calculation of dry weight conversion efficiencies of 17 and 18%, although the possibility of additional food entering the cages (*eg*, as plankton) cannot be totally excluded. Growth measurements were continued on these fish for 157 days, until a mean of 142 g had been attained; during the last 52 days the fish were fed a mixture of squid and trout chow. The mean water temperature during the 157 days was 26·5°C (range 23·3–29·9°C). A second group of fish held in a cage was monitored for 211 days, during which time they grew from 77 to 294 g, which is a marketable size. These fish received a combination of squid and trout chow for the first 145 days, and only trout chow for the last 66 days. The mean water temperature during the 211 days was 24·0°C (range 22·0–27·0°C). Mortality in the two groups of fish was negligible. Data from these two groups have been combined (Fig. 1) to yield a growth curve for fish from the fry stage to marketable size. It is apparent that a marketable fish can be produced from 9 g fry in approximately 300 days at ambient temperatures in Hawaii.

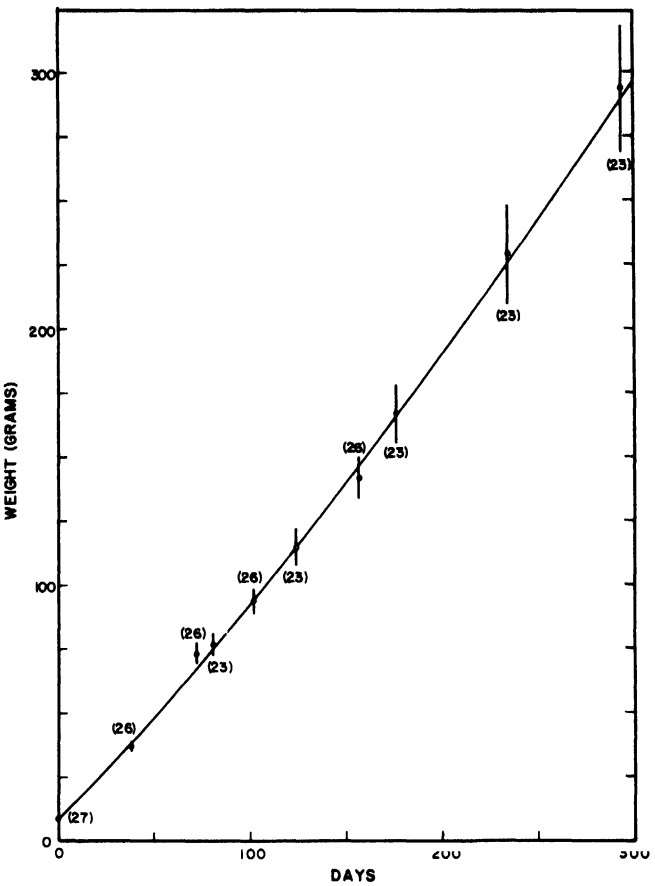


Fig 1. Growth curve for *Polydactylus sexfilis* from fry to marketable size. Data from two groups of fish (closed and open circles) have been combined to yield a single curve. Means and 95 per cent confidence intervals are plotted, with number of fish measured shown in (). The curve is the least squares fit to the power function ($y = 8{\cdot}8 + 51116x^{1{\cdot}1098}$)

4.3 *Optimal temperature and salinity*

Rao and Santerre (in preparation) studied the influence of temperature and salinity in a composite factorial array on the growth, food conversion and body composition of juvenile *P. sexfilis* of 8 to 20 g wet weight. Commercial trout chow was used as food. Their results suggested a thermal optimum at 27–28°C and a salinity optimum at approximately 25‰, with maximum dry weight conversion efficiencies of 18%. Thus growth and food conversion can be improved over the figures quoted above, even without improved diets, if environmental control can be exercised.

5 Discussion

P. sexfilis is considered an excellent food fish in Hawaii and commands a high market price. Since spontaneous

spawning occurs among captive fish, the elaborate procedures required to induce spawning in some species are unnecessary. The lunar spawning rhythm makes the time of spawning predictable, and the protracted natural spawning season assures a supply of eggs over at least half the year. Like certain other polynemids (Hida, 1967), *P. sexfilis* is a protandrous hermaphrodite (Morris, 1964; Lowell, 1971); this characteristic is advantageous in culture, in that fish will be harvested as males before significant amounts of energy have been shunted away from growth into egg production.

The rapid growth rates and efficient food conversion which have so far been documented for captive fish are extremely encouraging, especially when one considers that the specific nutritional requirements of *P. sexfilis* are still unknown. The fish's acceptance of artificial dry feeds means that dietary composition can be manipulated with the goal of producing a cost-effective diet which can be compounded locally. Where practicable, control of temperature and/or salinity can be expected to enhance growth and food conversion. The above set of characteristics make *P. sexfilis* a uniquely attractive fish for aquaculture.

P. sexfilis is truly Indo-Pacific in distribution. Although it occurs naturally in Hawaii, the species was originally described from Mauritius (Cuvier and Valenciennes, 1831) and has been recorded from as far west as Zanzibar (Playfair, 1866). Polynemids support major fisheries in Africa (Longhurst, 1965) and India (Kagwade, 1970) and are highly regarded food fish wherever they occur. Hence techniques for culturing *P. sexfilis* in Hawaii may be adapted, if not directly applicable, to the same or other polynemid species in other parts of the world.

In addition to the obvious need for refinements in larval rearing techniques and artificial diets, several subjects for future research with *P. sexfilis* hold special interest. The possibility of maintaining spontaneous spawning in tanks for extended periods of time should be studied, along with the roles of environmental cues in synchronizing the natural spawning rhythm. Exposing spawners to altered temperature and photoperiod regimes should be investigated as a means of artificially extending the spawning season. The protandry displayed by *P. sexfilis* opens the intriguing possibility that, through cryopreservation, sperm from individual fish can be used for self-fertilization and the quick development of inbred lines. In view of the information reported here for *P. sexfilis*, it would seem well worth while to examine more closely the aquacultural potential of other polynemid species.

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Flavour Problems in Fish Culture

Richard T. Lovell

Abstract

Environment-related off-flavours, usually of an earthy-musty type, are a chronic problem in intensive fish culture. A pond survey revealed odour-producing algae and actinomycetes in ponds with off-flavour channel catfish (*Ictalurus lacustris*). Incidence of off-flavour was independent of season, location, or density of algal bloom. Aquarium studies with mono-specific cultures of geosmin-producing algae indicated that catfish can absorb off-flavour compounds exclusive of the digestive tract. Geosmin was absorbed at sensory detectable levels within 24 hours. Off-flavour can be purged from catfish relatively quickly by holding in clean water for 4–14 days. Temperature influences rate of flavour removal and also rate of weight loss by the fish.

Problèmes gustatifs en pisciculture

Résumé

Les défauts de saveur liés à l'environnement—en général goût de terre ou de moisi—constituent un problème chronique en pisciculture intensive. Une enquête dans des étangs à révelé la presence d'algues et d'actynomicètes qui confèrent une saveur désagréable aux ictaluridés (*Ictalurus lacustris*). Ce phénomène est indépendant de la saison, du site ou de la densité de l'efflorescence d'algues. Les études en aquarium réalisées sur des cultures monospécifiques d'algues productrices de géosmine ont indiqué que les ictaluridés peuvent absorber des composés malodorants autrement que par leur tube digestif. La géosmine a été absorbée en quantités objectivement décelables en 24 heures. Il est possible de débarrasser les ictaluridés de leur mauvais goût en les maintenant en eau propre pendant 4 à 14 jours. La température influe sur le taux d'élimination de la saveur ainsi que sur le taux de deperdition de poids du poisson.

Problemas de sabor en la piscicultura

Extracto

Un problema crónico en la piscicultura intensiva son los sabores desagradables, usualmente de tipo fangoso-rancio, derivados del medio ambiente en que se crían los peces. En un reconocimiento hecho en estanques de cría de bagre de canal (*Ictalurus lacustris*) de sabor desagradable se observaron algas y actinomicetos odorígenos. La incidencia de los sabores desagradables resultó ser independiente de la estación, el lugar o la densidad de las floraciones de algas. Algunos estudios hechos en acuario con cultivos monoespecificos de algas productoras de geosmina indicaron que el bagre puede absorber compuestos de sabor desagradable sin intervención del tubo digestivo. En 24 horas, los peces habian absorbido geosmina en cantidades detectables sensorialmente. Los bagres pueden depurarse de todo sabor desagradable con relativa rapidez, manteniéndolos en agua limpia durante 4–14 días. La temperatura influye en la rapidez de la eliminación de los sabores desagradables y también en la tasa de pérdida de peso de los peces.

1 Introduction

A serious and frequent problem in intensive fish culture is the absorption of objectionable flavour compounds by fish

from the culture environment. The fact that fish readily absorb organic and inorganic compounds through their gills and skin, as well as from the digestive tract, makes it understandable that some of the compounds synthesized by organisms that thrive in the highly enriched culture environment can have an adverse effect upon the flavour of fish flesh. The off-flavour that occurs most frequently, often rendering fish unmarketable, is described as 'earthy-musty' ('musty' or 'muddy').

Although environment-related off-flavour was observed in pond-raised fish centuries ago in China (Lovell, Smitherman and Shell, 1974) and is a universal phenomenon in farm-grown fish, aquacultural researchers have generally found other areas more stimulating than ascertaining causes and controls for 'mustiness' in fish. Since removal of off-flavour from affected fish prior to marketing (in most societies) is necessary, but inconvenient, management procedures that will minimize the incidence of environment-related off-flavour would be extremely valuable to fish culturists.

2 History

Thaysen (1936) first described 'musty' flavour in fish in studies of trout taken from rivers in Scotland. He attributed the cause of the off-flavour to *Actinomyces* which grew in mud that was high in organic matter along the river bank. He demonstrated that trout could absorb compounds from water which were produced by an odoriferous *Actinomyces*. Aschner, Laventer and Chorin-Kirsch (1969) reported that a blue-green alga, *Oscillatoria tenuis*, was responsible for a disagreeable 'earthy' flavour in carp (*Cyprinus carpio*) which made the fish unacceptable in Israel. They recommended holding the off-flavoured fish in clean, flowing water for several days prior to marketing to improve the flavour.

Lovell (1971) reported that a characteristic, objectionable 'earthy-musty' flavour is frequently found in intensively-cultured channel catfish (*Ictalurus punctatus*) in the south-central and southeastern USA. A survey of the catfish processing industry (Lovell, 1972) showed that in the autumn of 1971 several large-scale processors reported that over 50% of the ponds tested before being drained contained fish with such intense off-flavour that harvesting was postponed until the flavour improved. Heavy concentrations of odour-producing actinomycetes or blue-green algae have been identified from ponds with 'earthy-musty' flavoured catfish, and are suspected of being the organisms responsible for the off-flavour (Lovell, 1972). Conversely, on many occasions off-flavoured fish have been found in ponds which contained actinomycetes and algae not unlike the aquatic flora in ponds where fish had normal flavour. Off-flavour-producing algae and actinomycetes have been found to produce noxious odours or flavours under one set of conditions but not under other conditions (Leventer and Eren, 1969; Lovell, 1971). This contributes to the complexity of defining the etiology of the off-flavour problem in fish.

Iredale and Shaykewich (1973) reported that commercial rearing of rainbow trout (*Salmo gairdneri*) in prairie lakes in central Canada has been impeded by the occurrence of 'muddy' flavour in fish from some lakes. They found that certain smoking and canning processes can effectively reduce the intensity of 'muddiness' in the fish. Off-flavour has been a common problem in carp ponds in China, Japan and Europe for many years (Lovell, Smitherman and Shell, 1974) and the traditional solution has been to hold the fish in clean water for a period until the flavour becomes acceptable.

The compound(s) responsible for the 'earthy-musty' flavour in fish apparently is geosmin, a highly odorous, colourless, neutral oil with a molecular formula of $C_{12}H_{22}O$ (Gerber and Lechevalier, 1965), or chemically related metabolites synthesized by aquatic micro-organisms. Gerber and Lechevalier (1965), Medsker, Jenkins and Thomas (1968) and Rosen, Mashni and Safferman (1970) isolated the 'earthy-musty'-smelling metabolite, geosmin, from several actinomycetes. Safferman *et al* (1967) discovered that the blue-green alga *Symploca muscorum* produced geosmin, and Medsker, Jenkins and Thomas (1968) showed that another alga, *Oscillatoria tenuis*, also produced this compound. Other odorous compounds isolated from actinomycete cultures or natural waters, which differ slightly from geosmin, are mucidone (Dougherty, Campbell and Morris, 1966) and 2-methylisoborneol (Rosen, Mashni and Safferman, 1970). Recently, Yurkowski and Tabachek (1974) isolated geosmin from rainbow trout and identified it as the principal compound responsible for the muddy flavour in farmed fish from lakes in Canada. Source of the geosmin was not determined.

Personal observations indicate that off-flavour is a chronic problem in recirculating raceway systems. Although causative organisms have not been identified, actinomycetes growing on organic sludge below the biofilter are a probable source.

3 Etiology

3.1 *Pond observations*

Research on off-flavour in pond-grown channel catfish has been in progress at Auburn University since 1971. During a two-year period, a pond survey was made to identify conditions and organisms associated with the 'earthy-musty' flavour problem that often occurred in fish from intensively fed ponds.

The first year, fish were collected from commercial ponds where farmers or processors reported off-flavour fish, and they were evaluated for intensity of off-flavour. An evaluation scale was established and judges were conditioned and selected on the basis of their ability to perceive the geosmin-type odour in prepared solutions and in fish. In the survey, and in all subsequent sensory evaluations of fish for 'earthy-musty' flavour, the fish were cleaned and dressed, wrapped in aluminium, and cooked without seasoning for 15 minutes at 250°C. Initially, the evaluators compared the suspect off-flavour fish against control fish with no off-flavour in triangle difference tests prior to assigning a numerical rating to fish with established off-flavour. As the evaluators gained experience, it was found that the initial difference test was not necessary. The evaluators assigned each sample a score of 1 to 10 according to the following scoring system: 10 = no off-flavour; 8 = slight; 6 = distinct; 4 = intense; and 2 = extreme. In addition to sensory evaluations, other information obtained included date, location of pond, water temperature and total hardness (as $CaCO_3$), condition of plankton bloom, predominant algae, and presence of odorous actinomycetes. Samples of water, mud and residue from the fish's stomachs

were cultured on actinomycete-specific agar plates and colonies grown on the plates were tested sensorily for odorous volatiles.

Forty-two alleged off-flavour ponds were surveyed. Most contained fish with slight to extreme off-flavour that was highly characteristic of the geosmin-type odour. The survey revealed very little conclusive information regarding season, geographic location, pond condition or types of organisms associated with off-flavour in the fish, but the following generalizations were made regarding incidence of 'earthy-musty' flavour in pond-culture channel catfish: (*i*) Off-flavour was found during all periods of the growing season. (*ii*) Off-flavour was found in ponds in hilly areas with low-productivity, sandy soils and low water hardness and in ponds in fertile loam and clay soils with higher water hardness. (*iii*) Off-flavour was not related to intensity of plankton bloom or occurrence of a plankton die-off. (*iv*) Off-flavour was not consistently related to a specific alga or to an odour-producing actinomycete. Generally, algae in the off-flavour ponds were similar to those found in ponds where fish did not have off-flavour. Odour-producing actinomycetes were found frequently in off-flavour ponds but were found as often in ponds with fish having no off-flavour. (*v*) Off-flavour in ponds in hilly, acid soils with soft water usually occurred early or late during the growing season when the water temperature was around 20°C or slightly lower, whereas ponds in the more fertile clay and loam soils with higher water hardness had off-flavour fish during all periods of the growing season.

In 1973, channel catfish from 40 ponds on the Auburn University Fishery Research Station were removed at various times during the year and evaluated for off-flavour. In the early spring, fish in three ponds had a distinct 'earthy-musty' flavour. Each of these ponds had heavy blooms which were almost exclusively the blue-green alga *Anabaena circinalis*. Fish from a pond without off-flavour were placed in a floating cage in one of the ponds with the *A. circinalis* bloom and allowed to stay for 1, 2, 4, 7 and 14 days. After one day the fish had a distinct flavour as determined by a panel of four experienced evaluators, and at seven days the off-flavour was intense. No off-flavour was detected in fish from any ponds during the summer or early autumn. In late autumn off-flavour fish were found in one pond with a heavy bloom of *A. circinalis* and in two ponds with intense growths of *Volvox aureus*.

No odorous actinomycetes were found in the off-flavour ponds. Of the forty ponds evaluated, most had algal blooms; however, only two algae, *A. circinalis* and *V. aureus*, both found in cool weather (< 20°C), could be associated with the 'earthy-musty' flavour in catfish.

3.2 *Controlled studies*

Although blue-green algae have frequently been suggested as causes of 'earthy-musty' flavour in pond-cultured fish, such an association has not been established under controlled conditions. A study was conducted at Auburn University (Lovell, 1972) to determine the capability of geosmin-producing blue-green algae to impart the 'earthy-musty' flavour in the flesh of channel catfish. Cultures of geosmin-producing blue-green algae *Symploca muscorum* and *Oscillatoria tenuis*, obtained from the Federal Water Quality Control Laboratory in Cincinnati, Ohio, and 50 g channel catfish were held in 150 litre stainless steel tanks containing luxuriantly growing dense masses of these algae. To measure the rate of off-flavour development in the tanks, four fish were collected from each of two tanks of *S. muscorum* and four from each of the two tanks of *O. tenuis* at 1, 2, 4, 6, 10 and 14 days after stocking. After each collection the fish were quick-frozen and stored in hermetically sealed pouches at −23°C for subsequent sensory analysis. To determine time required to purge the fish of any flavour acquired from the algae, catfish were held in two tanks of *S. muscorum* for 14 days, then removed and placed in charcoal-filtered, flowing water. The fish were removed from the flowing water after 0, 3, 6, 10 and 15 days and quick-frozen for subsequent analysis.

To determine the ability of fish to absorb the flavour compounds from the water without having an opportunity to ingest the algae, two 'algae-free' tanks were stocked with fish. Water passed from two *S. muscorum* culture tanks into the algae-free tanks by gravity through a glass wool filter, and was exchanged between the tanks twice daily. The algae tanks and the algae-free tanks were both enriched with nutrient solution; consequently, exchange of water between the two tanks did not dilute the nutrient concentration in the algae tanks. Fish were removed from the algae-free tanks according to the same schedule as was followed with the fish taken from the algae tanks.

After all samples had been collected, the frozen fish were thawed, dressed and cooked for sensory evaluation for 'earthy-musty' or algae-related flavour by a taste panel composed of four trained, experienced evaluators.

Within one day, the fish from the *S. muscorum* tanks had developed a distinct 'earthy-musty' flavour, similar to the odour of the algae, which became stronger at two days and reached maximum intensity at ten days (Table I). Algae-related flavour was only slight, but significant ($P < 0.05$), in fish from the *O. tenuis* tanks at two days and reached a maximum at 14 days, but never equalled the intensity of that in the fish from the *S. muscorum* tanks. Stomach contents of the fish revealed that moderate amounts of both algae were eaten during the first day they were in the culture tanks.

TABLE I

AVERAGE SENSORY PANEL SCORES FOR CHANNEL CATFISH HELD FOR VARIOUS PERIODS OF TIME IN EITHER TANKS CONTAINING CULTURES OF *S. muscorum* OR *O. tenuis* ALGAE, OR TANKS CONTAINING ALGAE-FREE WATER[1]

Tank environment	*Holding time (days)*						
	0	*1*	*2*	*4*	*6*	*10*	*14*
Symploca muscorum	9·8	6·8	5·5	5·7	5·7	2·8	3·0
Oscillatoria tenuis	9·0	8·5	8·0	6·8	6·7	6·6	4·7
Algae-free	9·0	9·1	—	8·8	8·5	6·0	5·3

[1] Score description: 10 = no off-flavour; 8 = slight; 6 = distinct; 4 = intense; 2 = extreme.

The fish exposed to the algae-free filtrate from algae culture tanks developed a flavour qualitatively similar to that of the fish held in direct contact with the algae. This indicated that the fish were able to absorb the dissolved geosmin-like compounds from the water, primarily across the gill membrane, into the blood. Absorption of the off-flavour compounds was appreciably slower by fish held in the algae-free filtrate than by those held in the algae culture tanks (Table I). Evidently, acquisition of algae-related off-flavour by channel catfish is greatly facilitiated when the fish ingest the algae.

This study presents evidence that channel catfish absorbed compounds synthesized by two species of geosmin-producing blue-green algae which imparted an 'earthy-musty' type of flavour in the fish, and supports the contention that some blue-green algae are probably important causes of off-flavour in commercially cultured catfish. Catfish apparently can absorb and subsequently deposit in their flesh sensorily detectable quantities of the flavorous compounds within 24 hours after being exposed to a significant amount of the algae growth, particularly if the algae cells are in dense masses so the fish can feed on them.

4 Control of off-flavour

4.1 *Removal of off-flavour from pond-cultured fish*

Three collections of off-flavour channel catfish from commercial ponds were delivered to the Auburn University Fisheries Research Laboratory and held in flowing, charcoal-filtered water at 16, 22, or 26°C. The fish were weighed and evaluated for flavour by six experienced judges, using the evaluation scale discussed previously, at 0, 3, 6, 10 and 15 days. Changes in flavour and weight of the fish are shown in Table II.

The data show that at 16°C between 10 and 15 days were necessary to render the fish free of off-flavour. During this period, weight loss was less than 9%. At 22°C the fish had lost most of the off-flavour between 6 and 10 days but weight loss was 10 to 13%. At 26°C flavour change was about the same as at 22°C but weight loss was 15 to 17% by the time the flavour was reduced to a tolerable level.

These results indicate that pond-absorbed 'earthy-musty' flavour can be purged from the fish in 5 to 15 days, depending upon water temperature and intensity of off-flavour in the fish. However, concomitant with off-flavour removal will be a weight loss ranging from 9 to 17%.

4.2 *Removal of geosmin from aquarium-cultured fish*

The channel catfish held in the tank containing the geosmin-produced alga *S. muscorum* for 14 days, as discussed previously, were subsequently transferred to a tank containing flowing, charcoal-filtered water at 25°C. After 3, 6, 10 and 15 days the fish were removed and evaluated for flavour by four experienced judges. As shown in Table III, after three days in clean water the flavour had improved significantly ($P < 0.05$). After ten days, the flavour was not significantly ($P < 0.05$) different from that of control fish. These results indicate that fish with intense 'earthy-musty' flavour caused by geosmin can be 'cleaned' within a ten-day period at 25°C by separating the fish from the source of the compound. Apparently, and fortunately for fish culturists, this lipid-soluble, odorous compound is rapidly mobilized from its storage sites in the fish's body.

TABLE III

AVERAGE SENSORY PANEL SCORES FOR CHANNEL CATFISH HELD IN TANKS CONTAINING *S. muscorum* FOR 14 DAYS AND SUBSEQUENTLY HELD IN FLOWING, CHARCOAL-FILTERED WATER FOR VARIOUS PERIODS OF TIME, AND FOR CONTROL FISH IN FLOWING WATER ONLY[1]

	Holding time in flowing water (days) at 25°C					
	0	*3*	*6*	*10*	*15*	*Control fish*
Sensory score	3·2	5·7	6·7	8·7	9·0	9·1

[1] Score description: as in Table I.

4.3 *Practical controls for off-flavour in fish*

Control of environment-related off-flavour in cultured fish concerns three areas: control of off-flavour in the culture system; removal of off-flavour from the fish after they have developed it; and utilization of off-flavour fish in a process that will mask the flavour.

Control of off-flavour in the culture system is a difficult task in that a highly enriched aqueous medium favours the growth of micro-organisms which synthesize the 'earthy-musty' compounds. Suggested control practices include the following:

(*i*) Minimize feed wastes by using good feeds and feeding practices. Growth of geosmin-producing micro-organisms is stimulated by unconsumed and unabsorbed organic nutrients (for actinomycetes) and inorganic nutrients (for algae).

(*ii*) Exchange of water through the culture system will remove unused nutrients and minimize the growth potential for off-flavour-causing micro-organisms. It will also reduce the concentration of micro-organisms and off-flavour compounds in the water.

(*iii*) Chemical control of blue-green algae in catfish ponds is being practised by some farmers in the United States although there are no established guidelines. Periodic application of 0·67 kg/ha of copper sulphate crystals controlled the growth of *Microcystis* in fish ponds at Auburn, Alabama (Crance, 1963); however, this rate was not effective in catfish culture ponds in Mississippi, where the water hardness was greater. Variations in water chemistry, density and species of algae, and management practices make general recommendations for chemical controls difficult. Permanent elimination of phytoplankton blooms in pond culture is undesirable. However, keeping the bloom thinned may reduce the incidence of off-flavour, or killing off the algae a few days prior to harvest may be helpful when off-flavour is present. Until safe recommendations are established, chemical control of algae should only be practised where compensatory measures can be taken in the event of an oxygen depletion resulting from an overkill of phytoplankton.

TABLE II

AVERAGE FLAVOUR SCORES AND WEIGHT CHANGES FOR OFF-FLAVOUR CHANNEL CATFISH HELD IN FLOWING, FILTERED WATER[1]

Water Temp. °C	*0 days*		*3 days*		*6 days*		*10 days*		*15 days*	
	Score	*Wt.* (%)	*Score*	*Wt.* (%)	*Score*	*Wt.* (%)	*Score*	*Wt.* (%)	*Score*	*Wt.* (%)
16	4·7	100	6·1	95	7·1	93	7·4	92	9·1	91
22	4·9	100	7·0	90	8·7	90	9·3	87	9·6	85
26	5·0	100	7·7	87	8·7	85	9·6	83	9·6	82

[1] Score description: as in Table I.

(*iv*) Increasing turbidity or muddiness of pond water through mechanical agitation or with bottom-feeding fish will reduce phytoplankton growth. The suggestion has also been made that suspended clay particles may act as adsorbants for the off-flavour compounds.

Removal of off-flavour from fish can be undertaken as follows:

(*i*) Off-flavour in ponds is usually, but not always, short-lived and will disappear in time. For lack of a better practice, catfish farmers in the United States usually leave off-flavour fish in the ponds until the flavour improves. When this is done the fish should be fed to prevent them from eating detritus and other materials that may augment the problem. When possible, water in the pond should be exchanged as often as is practical.

(*ii*) Remove fish from the off-flavour pond and place them in a clean pond or a holding tank with flowing water. The flavour will be acceptable after 5 to 14 days, depending upon intensity of the off-flavour and temperature. If possible the fish should be moved to where they can be fed to avoid a 9 to 17% weight loss.

(*iii*) Meade (1975) found that adding salt to water in a closed system raceway, to achieve a salinity of 10 ppt, several days before harvesting the fish solved the off-flavour problem that is usually associated with this culture method. The salinity destroyed the micro-organisms, probably actinomycetes, growing in the sludge below the filter.

Processing off-flavour fish through the following techniques also improves the final product:

(*i*) Iredale and Shaykewich (1973) and Lovell (1972) found that smoking for 5 to 6·5 h with simultaneous cooking partially masked the 'earthy-musty' flavour of rainbow trout and channel catfish respectively so as to make them acceptable to consumers.

(*ii*) Iredale and Shaykewich (1973) reported that steam precooking of fillet strips of rainbow trout and subsequent addition of vegetable oil before canning eliminated the 'earthy-musty' flavour.

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Fish Diseases and their Control in Aquaculture

S. Sarig

Abstract

During the last decade, research, advancement in methods of eradication of pathogenic organisms as well as the improvement of environment, have resulted in better conditions for commercial fish culture in ponds. However, with the increasing tendency to culture aquatic organisms more intensively, disease still remains one of the major problems in aquaculture. Not only does it result in economic losses due to heavy mortalities, but it also affects: growth and condition factor; resistance to fatigue (stamina); fecundity; vulnerability to predation; susceptibility to sub-optimal environmental factors; and blood changes.

The major diseases and associated problems in fish culture are described for parasites (ecto- and endoparasites), bacteria, viruses and toxic algae, as well as the various techniques for controlling diseases which include immunization, prevention, increase of 'natural' or genetic resistance, manipulation of environment, prophylactic use of chemicals, and therapy after onset of disease.

It is concluded from this review that:

(*i*) Great advances have been made in the chemotherapy of pathogenic parasites. However, the lag in qualified manpower, laboratory facilities and bureaucratic restrictions may serve as limiting factors in certain countries.

(*ii*) Advances in histology, identification of disease-promoting agents and use of medicated feeds assist in the control of many diseases of bacterial origin. There are still some problematic bacterial diseases which require further investigation related to their identification, life cycles, and methods of control.

(*iii*) Although many fish diseases of viral origin have been described in the past few years, there have been no real advances in their control.

(*iv*) Many fish diseases are the result of, or are enhanced by, poor environmental conditions and improper pond or hatchery management. This indicates that prophylaxis, proper care of the fish stock, and correct management are decisive factors in preventing the development of various diseases. This is especially important for future intensification of aquaculture.

(*v*) Both national and international control of the spread of fish disease through transference and introduction of live fish and fish eggs is needed.

Le contrôle des maladies des poissons en aquaculture

Résumé

Au cours des dix dernières années, grâce à la recherche, aux progrès des techniques utilisées pour détruire les organismes pathogènes ainsi qu'à l'amélioration du milieu, l'élevage des poissons en étang a pu se faire dans de meilleures conditions. Cependant, comme l'aquaculture est devenue de plus en plus intensive, les maladies en constituent désormais l'un des principaux problèmes. Elles n'entraînent pas seulement des pertes, sur le plan économique, du fait de taux élevés de mortalité, mais elles agissent également sur d'autres facteurs: la croissance et l'état de santé; la résistance à la fatigue; la fécondité; la vulnérabilité aux prédateurs; la sensibilité aux défauts de l'environnement; et les modifications hématologiques.

On trouvera dans cette étude une description des principales maladies dues à des parasites (ectoparasites et endoparasites, bactéries, virus et algues toxiques) en même temps que des problèmes qui s'y rattachent, ainsi que des différentes techniques utilisées pour lutter contre ces maladies: immunisation, prévention, accroissement de la résistance génétique ou 'naturelle', manipulation de l'environnement, utilisation prophylactique de produits chimiques et soins lorsque la maladie s'est manifestée.

Cette étude aboutit aux conclusions suivantes:

(*i*) De grands progrès ont été accomplis dans la chimiothérapie des parasites pathogènes. Néanmoins, dans certains pays, le manque de main-d'oeuvre qualifiée, d'installations de laboratoire ainsi que les

difficultés occasionnées par la bureaucratie s'opposent au succès de ces méthodes.

(*ii*) La lutte contre de nombreuses maladies d'origine bactérienne a également profité des progrès accomplis dans l'histologie, de l'identification des agents de diffusion des maladies et de l'utilisation de médicaments mélangés aux aliments. Il existe encore un certain nombre de maladies bactériennes mal connues dont l'identification, les cycles de vie et la thérapeutique exigeront de nouvelles recherches.

(*iii*) Bien que ces dernières années on ait décrit de nombreuses maladies des poissons d'origine virale, leur thérapeutique n'a pas fait de véritables progrès.

(*iv*) De nombreuses maladies des poissons sont, soit provoquées, soit aggravées par de mauvaises conditions mésologiques ou un entretien insuffisant des étangs ou des stations d'alevinage. Ce qui montre bien que des mesures prophylactiques, les soins apportés au stock de poissons et l'entretien correct du milieu sont des facteurs décisifs dans la prévention des diverses maladies. Il s'agit-là d'un point particulièrement important pour l'intensification future de l'aquaculture.

(*v*) Il serait extrêmement important de prendre, aux plans national et international, des mesures pour éviter la contagion des maladies, que peut provoquer la transplantation des poissons ou des oeufs de poisson.

Enfermedades de los peces en la acuicultura y lucha contra ellas

Extracto

Durante el último decenio, la investigación, los progresos en los métodos de erradicación de organismos patógenos y la mejora del medio ambiente han permitido crear mejores condiciones para la piscicultura comercial en estanques. Sin embargo, dada la creciente tendencia a cultivar organismos acuáticos con mayor intensidad, las enfermedades siguen siendo uno de los principales problemas. Además de ser causa de pérdidas económicas por las graves mortandades que producen, influyen también en el crecimiento y el factor de condición de los peces, su resistencia a la fatiga (estámina), fecundidad, vulnerabilidad a los depredadores y susceptibilidad a factores ambientales subóptimos, y determinan además alteraciones de la sangre.

Se describen las principales enfermedades—parasitos (ecto-y endoparásitos), bacterias, virus y algas tóxicas—y los problemas afines que plantean en piscicultura así como las diversas técnicas de control de enfermedades entre las que se incluyen inmunización, prevención, aumento de la resistencia 'natural' o genética, manipulación del medio ambiente, empleo profiláctico de productos químicos, y terapia una vez iniciada la enfermedad.

De este examen de la situación se concluye que:

(*i*) Se han realizado grandes progresos en la quimioterapia de parásitos patógenos. Sin embargo, la falta de mano de obra calificada y de laboratorios y las restricciones burocráticas pueden frenar el desarrollo de este sector en algunos países.

(*ii*) Los avances histológicos, la identificación de los agentes promotores de enfermedades y el empleo de piensos medicados ayudan a controlar las numerosas enfermedades de origen bacteriano. Existen aún algunas enfermedades bacterianas problemáticas, cuya individuación, ciclo vital y métodos de control exigen más investigaciones.

(*iii*) Aunque en los últimos años se han descrito muchas enfermedades de los peces de origen viral, no se han hechos verdaderos progresos en el control de esas enfermedades.

(*iv*) El mal estado del medio ambiente y el inadecuado manejo de estanques o viveros son causa de muchas enfermedades de los peces o contribuyen a agravarlas. Así pues, la profilaxis, el buen cuidado de las poblaciones de peces y el empleo de buenos métodos de manejo son factores decisivos para impedir la propagación de varias enfermedades. Esta cuestión tiene especial importancia en vista de la intensificación futura de la acuicultura.

(*v*) Es urgentemente necesario controlar a nivel nacional e internacional la propagación de las enfermedades de los peces debida a transferencia e introducción de peces vivos y huevos de peces.

1 Introduction

The supply of fish and other organisms from marine waters is rapidly reaching its limits. Inland waters such as rivers, lakes and reservoirs are becoming increasingly prone to pollution and their value as a source of supply of animal protein is decreasing. On the other hand, the world population, even in developing countries, is undergoing a rapid change toward urbanization, and man is becoming more and more dependent on a commercial supply of food through organized markets. Aquaculture with its great and as yet unexploited potential is therefore playing an ever-increasing role in the total food supply.

In order to exploit land and water economically for the production of animal protein, large numbers of finfish and shellfish must be cultivated in relatively small volumes of water on small areas of land. Under such conditions of unnatural crowding, it is inevitable that inimical conditions, enhancing the development of disease, will be encountered. The resulting loss of stock in such small areas (ponds, raceways, cages, pens, *etc*) may present a grave economic problem and constant effort is required to prevent such losses.

In order that infectious diseases manifest themselves, a potential pathogen must exist, a suitable host be present and proper environmental conditions occur which either bring about increased virulence of the pathogen or increased susceptibility of the host. Artificial stress conditions such as overcrowding, unbalanced nutrition, reduced oxygen content of water, an increase in organic material as well as changes in pH and temperature are factors which enhance the probability of diseases occurring among propagated fish.

During the last decade, research, advancement in methods of eradication of pathogenic organisms, and improvement of environmental conditions, have assisted in protecting fish stocks in commercial ponds. As compared to 10–20 years ago, we are not only better able to identify the harmful organisms, but we also know the measures to be taken to control many of them.

Nevertheless, due to intensified aquaculture, the problems have not lessened. Damage caused by disease is not only reflected in economic losses due to heavy mortalities but also affects the following: growth and condition coefficient (K-factor); resistance to fatigue (stamina); fecundity; vulnerability to predation; susceptibility to sub-optimal environmental factors; and blood changes (Hoffman, 1974).

The diseases prevalent under conditions of intensified aquaculture can be divided into five general groups: (*i*) ectoparasitic and fungal; (*ii*) endoparasitic; (*iii*) bacterial; (*iv*) viral; and (*v*) those due to organisms producing water soluble toxins or competing for dissolved oxygen (Sarig, 1971).

Since the beginning of the 1960s, efficient and simple chemotherapeutic methods have been developed in many countries where commercial fish culture has become firmly established. In many cases chemotherapy is almost unavoidable.

In general, chemotherapeutics can be subdivided into: (*i*) pesticides applied directly to the pond for the control of external parasites and fungi; and (*ii*) medicated feeds to arrest bacteria and endoparasites.

Increased use of pesticides in agriculture has also provided the fish farmer with chemicals distinguished by their selectivity toward various parasites. At the concentrations used, they are not harmful to the fish and cause little damage to aquatic food animals. This permits the introduction of new and simple methods for pest control by spraying the entire pond area with suitable compounds. Thus, the fish can be treated without being transferred from the pond. The quantities of pesticides required are usually relatively small, and the entire procedure is inexpensive and readily carried out. In commercial aquaculture, the value of the fish crop rises sharply so that losses in fish growth and mortalities are prohibitively more expensive than control and prophylactic measures.

When selecting new pesticides, the following factors have to be considered: the ratio between the lethal dose of the substance for the pest organism and that for the fish

must be sufficiently large, *ie*, at least 1:5; the substance must be simple to use, readily undergo complete dissociation in water, and be safe for handling; it should not be harmful to crops growing in the vicinity of the treated ponds; it should not significantly inhibit the productivity of the pond; the half-life of the pesticide should be extremely short in order to minimize unavoidable deleterious effects on the fish's food organisms; the cost of the pesticide must not be prohibitive; and the pesticide or other disease controlling agent should not become concentrated or stored in the fish flesh and must not be harmful to consumers of the treated fish. (Sarig, 1971).

The control of communicable diseases, bacterial or viral, can be achieved in several ways: (*i*) immunization; (*ii*) prevention; (*iii*) increase of 'natural' or genetic resistance; (*iv*) manipulation of environment; (*v*) prophylactic use of chemicals; and (*vi*) therapy after onset of disease.

An up-to-date appraisal reveals that: prevention, prophylaxis and chemotherapy have advanced considerably; immunization has not yet achieved satisfactory results since the immune response of fish is temperature-dependent and very slow; promising work has been started in genetic resistance but only in very few cases and on a limited scale (Herman, 1970).

Nevertheless, many shortcomings still limit the use of therapeutics, and misuse of medication may sometimes lead to negative results. In many countries, the use of chemicals in animal husbandry, fish included, is strongly restricted, and the release of quite efficient therapeutics is sometimes tedious, complicated and time consuming. Some compounds used for long periods of time may tend to accumulate in the body of the fish and adversely affect its development, or the fish consumer. If such a chemical has a long-term half-life in water, it may seriously retard the natural productivity of the water. The frequent use of medicated feed, especially antibiotics, may sometimes bring about complications. Under normal conditions, fish are under heavy stress during transportation and the change of environmental conditions. If fish are treated with antibiotics and then immediately transferred, they are weakened and their lowered resistance renders them prone to new infections. The market is flooded with advertisements of new chemicals; the use of chemotherapeutics without the consultation of a fish pathologist may lead to adverse results (Snieszko, 1964; Mann, 1975).

One of the routes of introduction of new diseases is via exotic fishes introduced for aquacultural purposes, for planting in natural waters or as aquarium stock. For example, the introduction of Chinese carp from the Far East to European countries has caused the spread of new epizootics such as swim bladder diseases, new bacterial gill diseases and damage due to new species of parasites (Mann, 1975). Another excellent example of the above was the introduction of Far Eastern fish species into the USSR, Czechoslovakia, German Democratic Republic, Romania, Poland and Hungary. Ten to fifteen years later, 28 species of parasites of Far Eastern origin were discovered in these countries. Nine of the species were found to be disease-producing and potentially pathogenic (Musselius and Strelkov, 1968).

This matter has been reviewed by Thompson, Dill and Moore (1973) with emphasis on the international measures required for the control of fish diseases transplanted between countries. A Symposium on the Major Communicable Fish Diseases in Europe and their Control, Amsterdam, 1972, considered the matter at length (Dill, 1973). As a follow-up of this Symposium, a Government Consultation on an International Convention for the Control of the Spread of Major Communicable Fish Diseases was convened in 1974 by FAO. As a result, a draft convention was prepared and sent to Member Governments for comment (FAO, 1974).

2 Parasites and fungal diseases

Research on the occurrence, identification and life history of freshwater parasites has been carried out almost the world over. Hoffman (1967) refers to some 1 200 papers on the parasites of North American freshwater fishes, and Kabata (1970), who deals only with crustacean parasites, refers to 200 related publications.

However, when methods of controlling harmful parasites are reviewed, the sources of information are limited. The classic works of Plehn (1924), Schäperclaus (1941), Davis (1933) and Hofer (1904), which appeared in the first half of this century, gave basic information on measures of parasite eradication, but in most instances this is inapplicable to modern, intensive, commercial aquaculture, the very existence of which may become precarious due to parasitic outbreaks. Only in the last 10–15 years have several helpful and updated books been published which take into account the circumstances and demands of modern aquaculture and apply modern therapeutic methods used in animal husbandry (Amlacher, 1961; Dogiel, Petrushevski and Pavlovski, 1961; Bauer, 1962; Reichenbach-Klinke and Elkan, 1965; Hoffman, 1967; Duijn, 1967; Ghittino, 1970; Snieszko, 1970; Sarig, 1971; Mawdeseley-Thomas, 1972; Roberts and Shepherd, 1974; and Hoffman and Meyer, 1974).

Parasites, and mainly ectoparasites, form the largest group of pathogenic organisms, especially in warmwater fishponds and in temperate climates. Long-term exposure to suitable temperatures and high levels of organic materials in pond water due to intensive fertilization and feeding enhance shortened life cycles and extensive infection by many pathogenic parasites, causing heavy mortalities. The increased density of fish populations in commercial ponds increases the possibility of epidemic outbreaks (Sarig, 1971).

The impact of parasite attack on fish stocks depends greatly on environmental conditions. An equilibrium naturally maintained between host and parasite may be disturbed by the occasional introduction of a new host or parasitic strain even of the same species. What are considered 'secondary' parasites may become dangerous and even fatal under different conditions. Therefore, no standard definition of host-parasite reactions can be taken for granted under changing conditions. Examples of such cases are very abundant in literature, and aquaculturists should give considerable importance to the aquatic parasitic fauna in the region.

Even fish stocks in natural waters or large bodies of water are vulnerable to parasitic infestations. The bream (*Abramis brama*) in the Tsimliansk Reservoir (USSR) serves as an example of such potential danger. This species was heavily infested with *Diagrama interrupta* resulting in a decrease of 25–30% in body weight and a reduction of 38% in fat content during its first year of life. The infested

fish did not spawn since gonadal development ceased (Bauer, 1962).

Ergasilus, a crustacean parasite, was present on fish in natural waters in Israel (Paperna, 1964a) but did not cause serious damage to the fish population. This parasite was similarly found in most African waters (Fryer, 1965) and there too no damage was recorded. In 1967, fishponds in Israel, with dense populations of carp, tilapia and grey mullets (*Mugil*), were infested with this parasite. After a short time, the mullets became extremely emaciated and suffered mortalities of up to 50%. The gills of these fish were covered with hundreds of parasites, but other fish species in the same pond were not affected (Sarig, 1971).

Monogenetic trematodes are very abundant in some parts of the world and constitute a considerable potential danger to intensive fish farming. In Israel, 29 species have already been described (Paperna, 1964) and in Africa, 71 species (Paperna and Thurston, 1969). One species of this group, *Dactylogyrus vastator*, is known to be highly dangerous for warm-water fish hatchlings a few days after hatching and up to the weight of about 3 g. Many heavy mortalities in spawning and nursing ponds have been described; millions of fry have been killed within 5–10 days. Such mortalities may sometimes cause the loss of the total annual production of a commercial farm if no replacement stocks are available (Sarig, 1971).

Protozoan parasites infesting fish have also been the object of intensive research in recent years. Schubert (1968) found *Costia necatrix* to be seriously affecting fish populations due to its ingestion of large numbers of epidermal cells. Other parasites of this group, such as *Chilodonella, Trichodina* and *Glossatella*, are also potentially dangerous, depending on the density of the fish stock and the massiveness of infestation. This group of parasites, as well as digenetic trematodes and parasitic crustacea whose outbreaks are temperature-dependent, are common to native fishes of Asia and Africa and there is already evidence of serious epizootics attributed to these parasites. Recently, increase in fish introductions as well as an increase in transfers within these continents has accelerated the pathogenic infestation of fish (Paperna and Thurston, 1969).

Chemotherapeutic treatment has been recently developed which enables the prevention or successful control of losses due to most ectoparasites. The possibility of carrying out such a measure against parasites attached to the fish by spraying chemicals directly onto the pond water without harming the fish, their growth, or the eventual consumers renders this method very suitable for use in commercial aquaculture and as a prophylactic measure during fish transport or import (Kabata, 1970; Sarig, 1971; Hoffman and Meyer, 1974).

Microscopic identification of parasites requires skilled and experienced workers, and the lack of manpower, laboratories and well organized extension services can aggravate the problem even when suitable control measures are known.

Changes in fishcultural procedures may sometimes influence the severity of certain diseases. Whirling disease, produced by the sporozoan *Myxosoma cerebralis*, is one example of such a development. The disease which infects salmonids, mainly rainbow trout (*Salmo gairdneri*), is spread throughout the world (Bogdanova, 1973). Heavy infestation may bring about high mortalities of small fish. Survivors become carriers, and spores in salmonids may survive for as long as 10–15 years. The parasite must spend up to six months in mud becoming 'conditioned' before it is able to parasitize rainbow trout and affect the head cartilage. It can only parasitize young fish, *ie*, before ossification of the skeleton, which occurs when the fish attain a length of 6–8 cm. The disease can be prevented by keeping the fry in concrete or fibreglass tanks provided with spore-free water, instead of in earthen ponds, until the fry reach a size of 6–7 cm (Christensen, 1973). Hoffman (1964) has found that spores in infested fish can be destroyed by ultraviolet light. Consequently, modern farming techniques can minimize the danger of this disease which, until recently, was considered one of the most severe diseases of salmonid culture.

Ceratomyxa shasta, another mixosporidian parasite causing mortalities of young salmonids in western US salmonid farms, has also proved to be highly sensitive to ultraviolet light; if treated accordingly, it is possible to practically clear contaminated hatchery waters (Hoffman, 1974).

The introduction of herbivorous fish from the Far East into western Europe was followed by an invasion of new parasites. Of these, *Bothriocephalus gowkongensis*, which infests grass carp (*Ctenopharyngodon idella*), is an example in that it is now found infesting the common carp (*Cyprinus carpio*) of the Federal Republic of Germany, causing mortalities of 25–30% in carp fingerling populations.

Khawia sinensis is another parasite imported from the Far East. It sometimes reaches a length of 7–8 cm and can be found in numbers exceeding 100 in the intestines of infested fish, sometimes blocking food intake and causing death due to starvation. The only effective control measure known is to dry the pond and lime it (with $CaCl_2$), measures which cause waste of time in commercial aquaculture (Mann, 1975; Musselius and Strelkov, 1968).

3 Bacterial diseases

Bacteria pathogenic to fish are divided into 'obligate' and 'facultative' pathogens. In examining bacterial infections of fish, it is essential to establish whether the isolated organism is a true pathogen of the fish or a secondary invader. Many common saprophytic water bacteria can produce diseases when the fish are under stress due to specific but as yet poorly understood environmental conditions which affect the susceptibility of the fish and pathogenicity of the bacteria. Obviously, host susceptibility, pathogen virulence and environmental conditions must all be favourable to bacteria for epizootics to occur in fish populations. Some factors affecting bacterial epizootics include: immunological resistance, genetic resistance, temperature stress, pollution, unfavourable water chemistry, and other unfavourable environmental conditions (Snieszko, 1964).

In hatcheries, the practical control of bacterial disease is problematic. One method to prevent it is through use of medicated feed. Roberts and Shepherd (1974) recommend Furanace (Nifurpinal) and Hyamine 3 500 (a quarternary ammonium compound) as being of particular value in treating bacterial diseases; these chemicals are readily sprayed on infected ponds. Deufel (1974) advocates treatment with Mefarol (identical to Roccal) in hatcheries for salmonids and pikes (*Esox*) for the control and prophylaxis of bacterial disease.

Bacterial diseases are more acute in cold-water aquaculture than in warm-water culture. Of the most important

pathogens, the following groups should be mentioned: (*i*) *Aeromonas* and *Pseudomonas*, (*ii*) Corynebacteria, (*iii*) Enterobacteria, (*iv*) Hemophilus, (*v*) Mycobacteria and *Nocardia*, (*vi*) Myxobacteria, (*vii*) Streptomyces, and (*viii*) *Vibrio*.

Although some authors have considered that *Aeromonas punctata* and other bacteria were the primary causative agents of infectious dropsy of carp (IDC), most authors have discounted this view and pointed toward viral origin (see Tomasec, 1973, and the findings of an expert panel on the subject as reported by Dill, 1972). It is evident, however, that replication of these bacteria (which are often found in fish with IDC) may influence the course of the disease. Fijan (1972) has recently shed new light on this disease by distinguishing it into two different epizootics, one caused by a virus—spring viremia of carp (SVC) and the other of bacterial origin—carp erythrodermatitis (CE). Although individual antibiotic injections have reduced the mortality rate in the case of the bacterial disease, the entire problem which is still unsolved continues to endanger cyprinids in intensive aquaculture (Popoff and Kinkelin, 1968; Lobountzov and Roudikov, 1968). The CE form responds to chemical treatment, for example, Furazolidane in a bath or oxytetracycline in the feed. These findings are of great importance as individual injections of antibiotics are not practical.

Aoki and Egusa (1971) and Aoki *et al* (1971 and 1971a) examined the resistance of *Aeromonas liquefaciens* and found that 39 out of 72 drug-resistant strains carried transferable drug-resistance factors, mainly to sulphanilamide and tetracycline. They believe that the high incidence of resistance factors in cultured fish is attributable to the high selective pressure exerted by the chemotherapeutics used in fish culture. According to Hoffman (1971), epizootics of *A. liquefaciens* also caused mortalities of *Salmo salar* and the white sucker (*Catostomus commersoni*) in natural waters. Environmental stress (pollution and high temperatures) enhanced conditions for an epizootic.

Furunculosis, which is caused by *Aeromonas salmonicida*, characteristically breaks out when water temperatures are at their peak, and is common mainly in salmon and brown trout (*Salmo trutta*), but less so in rainbow trout (*S. gairdneri*). It is transmitted by water from diseased or carrier fish, by contact by eggs and by equipment. It is treated by medicated feed to which chiefly sulphanamides, antibiotics or nitrofurons are added (Herman, 1973). Disinfection of ova, facilities, as well as other sanitary measures are of great importance.

Research is still required on chemotherapy through the addition of drugs to water and immunization.

Bacterial kidney disease (BKD), another disease causing losses, is probably confined to salmonids. Mortality increases with increased temperature. Diagnosis of the disease is quite complicated and transmission has not been unequivocally established. There is some evidence that transmission takes place through fertilized eggs (Bullock, Conroy and Snieszko, 1971). The causative agent seems to be a Corynebacterium. No effective control or treatment is known. Roberts and Shepherd (1974) claim that care should be taken to ensure that salmon eggs or parr come from an uninfested source.

'Redmouth' is another disease of rainbow trout found in the western US and caused by a still unnamed enterobacterium. The disease is known to be communicable. Although under experimental conditions immunization and chemotherapy with sulphamerazine and antibiotics gives promising results, there is practically no cure (Bullock, Conroy and Snieszko, 1971).

Ulcer disease caused by *Haemophilus piscium* affects trout in the northeastern United States and Canada. The main problem lies in the fact that the organism, transmitted by faecal material, can be carried by adult survivors. Although oxytetracycline keeps the epizootic under limited control, the main measures are prevention by adherence to strict sanitation (Bullock, Conroy and Snieszko, 1971).

Mycobacterium tuberculosis often causes great damage to salmonids fed salmon or trout viscera, but does not present a problem to modern farms which feed their fish with pelleted diets (Roberts and Shepherd, 1974). According to Bullock, Conroy and Snieszko (1971), the disease is encountered throughout the world and more than 120 species are susceptible to infection by this bacterial species. Treatment is usually not feasible, and control is effected by changing the method of feeding.

Reichenbach-Klinke (1972) subdivides pathogenic mycobacteria into two categories: (*i*) those infecting warm and temperate-water fish such as *Myxidium fortuitum* and *M. marinum*; and (*ii*) those infecting cold-water fish such as *M. salmoniphilum*. It is practically impossible to eradicate such infections, but their occurrence can be reduced by adequate nutrition, husbandry, and environmental conditions.

Myxobacteria are the source of many diseases, especially those of salmonids, producing: fin rot, tail rot, Columnaris disease, coldwater disease, peduncle disease and bacterial gill disease. The diseases may be aggravated by unfavourable conditions such as crowding, improper temperature and malnutrition. Necrosis caused by fin or tail rot serves as entry for more virulent pathogens. The introduction of oxytetracycline into the water is quite successful but not practical in large ponds. Therefore, the most recommended measures are improvement of environmental conditions and management (Bullock, Conroy and Snieszko, 1971; Roberts and Shepherd, 1974).

Columnaris causes special problems for aquaculturists in the USA, Japan and the United Kingdom because of its ability to persist for long periods at high temperatures and in the presence of increased water hardness and organic content. Thus, pathogenicity increases with intensification of industry (Fijan, 1968). Amend (1970) differentiates between highly virulent strains which may cause death within 24–48 hours and low virulence strains which bring about death after several days. In systematic infections, sulfonamide antibiotics or nitrofurans in the diet may be helpful.

Coldwater disease and peduncle disease are caused by *Cytophaga* sp. Therapy of coldwater disease is limited to feeding of medicated feeds. The best results have been obtained with sulfisoxazole and sulphamethazine in starter feed for fish fry and oxytetracycline in feeds for larger fish. When the disease appears in yolk-sac fry, medicated feed cannot be applied (Amend, 1970). Peduncle disease is limited to salmonids, but is less common in trout. Prevention can be brought about by reducing stocking density, rearing young salmonids in troughs, and treatment with sulfa drugs until the temperature rises (Bullock, Conroy and Snieszko, 1971).

Bacterial gill disease is produced by a variety of myxo-

bacteria, especially when fish are under stress. Roberts and Shepherd (1974) recommend the addition of Hyamine 3 500 to the water. Prophylactic measures such as improvement of environmental conditions are most helpful. Christensen (1972) also considers the avoidance of dusty feed to be important.

In eel farming, the following are the most pathogenic bacterial diseases: cotton wool disease and red fin disease, caused by *Aeromonas parasitica* closely associated with the fungus *Saprolegnia parasitica* in Japan (Egusa, 1968). Both organisms are known to cause heavy damage in warm-water aquaculture. Many problems concerning these epizootics are still unsolved and no easy nor reliable prevention or curative measures are known.

Vibriosis anguillarum is known to cause considerable damage to populations of all fish species cultured in salt water. Prompt treatment with antibiotics (nitrofurans) will usually save those fish still capable of taking food (Roberts and Shepherd, 1974).

Swim bladder inflammation (SBI) was first encountered in the USSR but has already spread over almost all of Europe. The disease appears mainly in densely populated and artificially-fed carp ponds but is also found in wild stocks. A virus is suspected as the causative agent but the etiology is uncertain. Although chemotherapy has been effective, the chief measure of control seems to be careful supervision of transported stock, quarantine and sanitary measures. (See especially Arshaniza and Bauer (1973), Liebmann (1973) and Antychowicz (1973).)

4 Viral diseases

Wolf (1972) indicates that in the last ten years, a number of severe fish diseases have been caused by viruses, and distinguishes eight particularly important viral diseases. Viral diseases cannot be cured and it is essential that they be controlled by preventive medicine.

Infectious haematopoietic necrosis (IHN) is a viral disease of salmonids confined to North America and Japan, causing heavy mortality of juvenile Pacific salmon (*Oncorhynchus*) and rainbow trout (*Salmo gairdneri*). It is a specific cold water disease, 15°C being the upper limit of infection. The virus can be transmitted by contact with infected fish, exposure to water from an infected source, and feeding on infected carcases, and can be borne on the surface of eggs from healthy, infected stock. Disinfection of the eggs by iodophores prevents transfer of the disease, but there is no cure for diseased fish. Practical control by incubation at an elevated temperature, 18–20°C for 4–6 days following the first 24 hours of infection or continued growth at 15°C aid in prevention (Amend *et al*, 1973).

Infectious pancreatic necrosis (IPN) is a very contagious disease of salmonids, especially young fry, endemic in most parts of North America, Europe and Japan. It is transmitted via eggs, milt or faeces. Adult fish may carry the virus within their internal organs, particularly the gonads, without any manifestations of disease. The disease may cause a loss of 20% of the stock and the surviving fish remain carriers for re-infestation. No remedy is known. In certain experiments, some chemotherapeutics effected a 50% reduction in mortality. The principal means of control is to provide infection-free stock (Christensen, 1972; Scherrer, 1973).

Viral haemorrhagic septicemia (VHS), or Egtved disease, is transmitted by contact and via infected water passing through the gills. Various stress factors influence the course of the disease. It is confined to Europe. It does not survive on fish eggs and carrier fish do not present a problem, thus facilitating prevention. Rainbow trout are very susceptible, and brown trout (*Salmo trutta*) appear to be resistant to this virus. The disease affects fish exceeding a length of 5 cm and is most common at low temperatures. As with other viral diseases, no treatment is known and if an outbreak occurs it is best to destroy the entire farm stock, leave the ponds fallow, and disinfect for three months before restocking. Research is required in vaccines for immunization and in development of resistant strains. Serological identification has been recently developed (Jørgensen, 1968; Ghittino, 1973; Christensen, 1972).

Ulcerative dermal necrosis (UDN) is a disease whose etiology is still uncertain, although work undertaken suggests that it is infectious and filterable. It affects adult Atlantic salmon (*Salmo salar*) and sea trout (anadromous form of brown trout). So far, the disease has been described in Ireland, Great Britain and France. The fungus *Saprolegnia* occurs as a secondary infection in the lesions of infected fish and causes heavy mortalities. In view of its probable infectious nature, it is advisable to take hygienic precautions against this virus (Murphy, 1973; Roberts and Shepherd, 1974).

Spring viremia of carp (SVC) has been recently separated from what is known as infectious dropsy of carp (IDC). SVC is caused by *Rhabdovirus carpio*. Epizootics occur in all of Europe during the spring season at temperatures of 13–22°C. The mode of transmission is not known and chemotherapy is nonexistent. The mortality among carp during epizootics may vary from very low to 90% (Fijan *et al*, 1971; Fijan, 1972; Tomasec, 1973).

The following diseases are also likely to be of viral origin, and can cause considerable damage to cultured fish populations:

(*i*) Great numbers of pike (*Esox lucius*) are found to contain tumours suggesting viral involvement. They resemble other epizootics—carp pox and tumours of pike-perch (*Stizostedion*) and flathead soles in the USA, as well as tumours of some fish species in the Japanese sea and the cauliflower disease of eels. No treatment is known (Winquist, Ljungberg and Hellstroem, 1968; Koops *et al*, 1970);

(*ii*) Channel catfish viremia (CCV) is a relatively new disease but it already effects heavy losses in *Ictalurus lacustris*. It has been definitely established that the vector is a virus (Fijan, 1968a; Wolf and Darlington, 1971);

(*iii*) Wolf, (1972) in his review of fish virology, enumerates 15 known fish diseases caused by viruses, in addition to the above-mentioned acute viremias and non-acute viral diseases (lymphocystis, walleye sarcoma, walleye epidermal hyperplasia, papillomas and cauliflower disease). Although it is unlikely that the non-acute viral diseases cause extensive mortalities, there is a possibility that there are early acute phases which could kill before the typical discernible symptoms develop; the debilitating effects of any disease may contribute to factors promoting fish death.

5 Toxic algae

Extensive information exists in literature on algal species which produce toxins that may kill fish. Smirnov and Fedokistova (1963) have reported the toxicity of the blue-

green alga *Coelosphaerium dubium* in British Columbia. Blooms of *Prymnesium parvum*, a flagellate, and certain blue-green algae, especially *Microcystis, Anabaena, Spirulina,* and *Oscillatoria* have killed pond fish (Shilo, 1965, 1971; Ulitzur, 1966; Sarig, 1968). Pathological changes due to toxins of *Cyanophyta* and records of fish killed by *Glenodinium* in a reservoir have also been reported.

As emphasized by Snieszko (1964) in regard to bacteria, environmental conditions are even more important in their effect on fish kills due to algal blooms. Changes in pH, CO_2 content and mainly oxygen depletion caused by excessive algal growth in ponds can effect massive fish mortality (Sarig, 1971; Swingle, 1968). While the control of the toxin-producing alga, *Prymnesium parvum*, can in most cases be easily controlled, no satisfactory economical measures are yet known for the control of excessive algal blooms.

6 Conclusions

Several important conclusions can be reached from this review:

(*i*) Great advances have been made in the chemotherapy of pathogenic parasites. However, the lag in qualified manpower, laboratory facilities and bureaucratic restrictions may serve as limiting factors in certain countries.

(*ii*) Advances in histology, identification of disease-promoting agents and use of medicated feeds assist in the control of many diseases of bacterial origin. There are still some problematic bacterial diseases which require further investigation related to their identification, life cycles and methods of control.

(*iii*) Although many fish diseases of viral origin have been described in the past few years, there have been no real advances in their control.

(*iv*) Many fish diseases are the result of, or are enhanced by, poor environmental conditions and improper pond or hatchery management. This indicates that prophylaxis, proper care of the fish stock and correct management are decisive factors in preventing the development of various diseases. This is especially important for future intensification of aquaculture.

(*v*) Both national and international control of the spread of fish diseases through transference and introduction of live fish and fish eggs is needed.

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Epidemic Fish Diseases and their Control in Japan

H. Kawatsu, A. Homma and K. Kawaguchi

Abstract

Fish cultivation is widely carried on in the freshwater and coastal areas of Japan. The principal fish cultivated in fresh water are salmonids, cyprinids, eel and ayu. Cultivated marine fish include yellowtail, seabream and penaeid shrimp. The control of fish diseases, both endemic and transferred from other countries through import of live fish and fish eggs, are of importance to this industry.

The problem of controlling epidemics becomes more serious every year. In 1973 the loss caused by fish disease to the total Japanese freshwater fish harvest of 64 000 tons was estimated at about 5 800 tons; the loss to the total marine fish harvest of 84 000 tons was about 3 500 tons.

Principal epidemic diseases are as follows: (*i*) in salmonids, vibriosis, fungus disease, IPN, IHN, hexamitiasis and furunculosis; (*ii*) in cyprinids, ulcer disease, columnaris disease and bacterial slime disease; (*iii*) in eel, branchionephritis, columnaris disease, red disease and red spot disease; (*iv*) in ayu, vibriosis and *Glugea*, and (*v*) in yellowtail, bacterial tuberculosis, vibriosis, nocardial infection and trematode infection.

Among the 'international fish diseases', IPN, IHN, furunculosis, gill necrosis, ulcers and cestode infection are present in Japan. Whirling disease, VHS, SV and swimbladder inflammation of cyprinids have never been recorded in Japan.

As international trade in live fish and fish eggs increases, the opportunities for introduction of exotic diseases are increased. The main items of Japanese live fish exports are goldfish, coloured carp and oyster seed. Eels, various marine fishes, shrimp, *etc*, are imported alive from many countries. At present, health certifications are not required to import live fish and fish eggs into Japan. But the Fisheries Agency has implemented a programme to establish a fish disease control system and at the same time a national act is in preparation to regulate the transportation and importation of all forms of aquatic life from foreign countries.

Les maladies épidémiques des poissons et leur contrôle au Japon

Résumé

On pratique largement la pisciculture dans les eaux douces et dans les eaux côtières du Japon. Les principaux poissons élevés en eau douce sont les salmonidés, les cyprinidés, l'anguille et l'ayu. Les cultures marines portent notamment sur les sérioles, les sparidés et les crevettes pénéides. La lutte contre les maladies des poissons, qu'elles soient endémiques ou qu'elles se propagent à la suite d'importations de poissons et d'oeufs de poisson, joue un rôle important pour cette industrie.

La problème de la lutte contre les epidémies s'aggrave d'année en année. En 1973, on a estimé à quelque 5 800 tonnes, sur une récolte totale de 64 000 tonnes dans les eaux douces japonaises, les pertes provoquées par les maladies des poissons; par ailleurs, les pertes ont atteint 3 500 tonnes sur une recolte totale en poissons marins de 84 000 tonnes.

Ci-après les principales maladies epidémiques: (*i*) chez les salmonidés, vibriose, maladie cryptogamique, NPI, NHI, hexamitiase et furonculose; (*ii*) chez les cyprinidés, maladie ulcérante, maladie columnaris, maladie bacterienne du mucus; (*iii*) chez l'anguille, branchioéphrite, maladie columnaris, maladie du rouge et des taches rouges; (*iv*) chez l'ayu, vibriose et *Glugea*; (*v*) chez les sérioles, tuberculose bactérienne, vibriose, infection du myocarde, et infection par les trématodes.

Parmi les maladies 'internationales' des poissons, NPI, NHI, furonculose, nécrose des ouïes, maladie ulcérante et infection par les cestodes sont présentes au Japon. Par contre, l'on n'a jamais enregistré dans ce pays les affections suivantes: maladie du tournis, SHV, SV et inflammation de la vessie natatiore des cyprinidés.

A mesure que s'intensifie le commerce international des poissons vivants et des oeufs de poisson, les possibilités d'introduction des maladies exotiques s'accroissent. Les exportations de poissons et de mollusques vivants japonais portent essentiellement sur le cyprin doré, la

carpe colorée et le naissain d'huître. Le Japon importe des anguilles, divers poissons marins, des crevettes, *etc.* à l'état vif en provenance de nombreux pays. A l'heure actuelle, l'on peut importer des poissons vivants et des oeufs de poisson au Japon sans produire un certificat sanitaire. Toutefois, l'Office des pêches a mis en oeuvre un programme destiné à lutter contre les maladies des poissons; par ailleurs, une loi est en préparation aux fins de réglementer le transport et l'importation de toutes les formes de vie aquatique en provenance de pays étrangers.

Enfermedades epidémicas de los peces y su control en el Japón
Extracto
En el Japón está muy extendido el cultivo de peces en aguas dulces y zonas costeras. Las principales especies cultivadas en aguas dulces son salmónidos, ciprínidos, anguilas y ayu. Entre los peces marinos cultivados figuran el pez limón, el besugo y los camarones peneidos. El control de las enfermedades de los peces, tanto endémicas como procedentes de otros países a través de la importación de peces vivos y huevos de peces, son de importancia para esta industria.

El problema para el control de epidemias es más serio de año en año. Se calcula que en 1973 las enfermedades de los peces hicieron perder a la industria piscícola japonesa de aguas dulces unas 5 800 toneladas, ante una producción de 64 000; las pérdidas en la piscicultura en aguas marinas, con una producción de 84 000 toneladas, fueron del orden de 3 500 toneladas.

Las principales enfermedades epidémicas son las siguientes: (*i*) en los salmónidos: vibriosis, micosis, necrosis pancreática infectiva, necrosis hematopoyética infectiva, hexamitiasis y forunculosis, (*ii*) en los ciprínidos: úlceras, infección de *Chondrococcus columnaris*, e infección bacteriana del mucus (*Pseudomonas fluorescens*); (*iii*) en la anguila: branquionefritis, infección de *Chondrococcus columnaris*, peste roja (*Aeromonas hydrophila*) y peste macular roja (*Pseudomonas anguilliceptica*); (*iv*) en el ayu: vibriosis y *Glugea*; y (*v*) en el pez limón: tuberculosis bacteriana, vibriosis, nocardiasis y infestaciones de trematodos.

De las 'enfermedades internacionales de los peces', existen en el Japón: necrosis pancreática infectiva, necrosis hematopoyética infectiva, forunculosis, necrosis branquial, úlceras, e infección de cestodos. Nunca se han registrado en cambio, en el Japón, casos de enfermedad del vértigo, septicemia hemorrágica viral, viremia primaveril e inflamación de la vejiga natatoria de los ciprínidos.

A medida que aumenta el comercio internacional de peces vivos y huevos de peces, aumentan las posibilidades de introducción de enfermedades exóticas. Las principales partidas de las exportaciones japonesas de peces vivos son carpa dorada, carpa de color y semilla de ostras. Se importan vivos de muchos países anguilas, varios peces marinos, camarones, etc. En la actualidad no son necesarios certificados sanitarios para importar peces vivos y huevos de peces en el Japón, pero la Oficina de Pesca ha implementado un programa para establecer un sistema de control de las enfermedades de los peces y, al mismo tiempo, está en preparación una ley nacional para regular el transporte e importación de todas las formas de seres vivos acuáticos procedentes de países extranjeros.

1 Introduction

As aquaculture expands throughout the world, there is greater traffic in and transfer of live fish and fish eggs from country to country. With such transfers, the opportunities for introduction of fish diseases and parasites is increased, and protection from infection by exotic diseases has become an urgent problem for aquaculturists.

This paper presents the status of fish diseases and the programme for their control in Japan. Emphasis is placed upon those diseases which are important economically and upon their prevention rather than treatment.

2 Production of cultivated fish in Japan

Fish cultivation is widely carried on in the freshwater and coastal areas of Japan (Table I). The principal fishes under cultivation in fresh water include salmonids (*eg*, rainbow trout, *Salmo gairdneri*), cyprinids (especially common carp, *Cyprinus carpio*), eel (*Anguilla*) and ayu (*Plecoglossus altivelis*). Harvests of these fish amounted to 97% of the 64 000 tons of freshwater fish harvested in 1973. The production of salmonids, carp and ayu is increasing. In contrast, the production of eels has remained at a lower level due to a shortage of elvers (used as seedlings) in recent years. Marine fish cultivation has developed rapidly during the last decade. The production of yellowtail (*Seriola quinqueradiata*), for example, exceeded 80 000 tons in 1973; this is a production 16 times greater than that in 1963. Although the amount of production is still small, the harvests of red sea-bream (*Pagrus major*) and penaeid shrimp (*Penaeus japonicus*) have increased remarkably since 1970. Cultivation of aquarium fishes, such as coloured carp and goldfish (*Carassius auratus*) is common in freshwater areas; the numbers of these produced in 1973 were 131 884 000 and 229 993 000 respectively (Japan, Ministry of Agriculture and Forestry, Bureau of Statistics (1975)).

TABLE I
PRODUCTION OF CULTIVATED FISH IN JAPAN

	1970	*1971*	*1972*	*1973*
Freshwater fishes		*tons*		
Salmonids	10 632	12 749	13 515	16 425[a]
Carp	15 865	17 840	23 037	26 409
Eel	16 730	14 233	14 089	15 247
Ayu	3 411	3 941	4 317	4 428
Coastal sea fishes				
Yellowtail	43 354	61 855	77 059	80 439
Sea bream	454	930	1 380	2 741
Other fishes	103	128	284	584
Penaeid shrimp	301	306	454	657
Aquarium fishes		*Thousands in number*		
Coloured carp	—	—	—	131 884
Goldfish	—	—	—	229 993

[a] This figure includes 715 tons of harvest of native land-locked trout
Source: Japan, Ministry of Agriculture and Forestry, Bureau of Statistics (1972, 1973, 1974 and 1975)

3 Important epidemic fish diseases in Japan

In the development of fish culture, considerable effort has been paid to the techniques of cultivation, improvement of diet and control of disease. As production has been extended, the problem of controlling epidemics, especially under conditions of high density stocking and rearing, has received more and more attention.

(*i*) *Salmonids:* With progress in knowledge of fish nutrition and improvements in the formulation and manufacture of artificial diets, dietary diseases of salmonids have almost disappeared. Nevertheless, loss of fish due to communicable diseases has tended to increase. Infectious pancreatic necrosis (IPN) and infectious haematopoietic necrosis (IHN) have caused serious damages in fry stages, and losses due to hexamitiasis (octomitiasis) are found in some localities. Vibriosis (*Vibrio*) is serious in stages from fingerling to adult. Recently, fungus disease has occurred in mature fish and the supply of eyed eggs has occasionally been infected. Furunculosis (caused by the bacterium *Aeromonas salmonicida*) is one of the most serious diseases of the native land-locked Japanese salmonids (*Oncorhynchus masou*, *O. rhodurus* and *Salvelinus pluvius*).

(*ii*) *Cyprinids:* Ulcer disease, columnaris disease and bacterial slime disease (caused by a non-motile variant of *Pseudomonas fluorescens*) are the principal epidemics in Japanese cyprinid cultivation. Since 1970, ulcer disease has occurred in various freshwater fishes, causing the heaviest damages in carp and goldfish cultivation. The etiology of ulcer disease has not yet been established and the relationship between this disease and the so-called carp erythrodermatitis (CE) of Europe, remains uninvestigated.

(*iii*) *Eel:* Branchionephritis, columnaris disease, red disease (due to *Aeromonas hydrophila*) and red spot disease (caused by *Pseudomonas anguilliceptica*) are the principal epizootics in eel cultivation. Branchionephritis began to

occur in Japan in 1970, and continued to cause heavy damages every winter. Recently, two kinds of pathogenic viruses were isolated from diseased eels (Sano and Nichimura, 1974; Sano *et al*, 1974).

(*iv*) *Ayu:* Vibriosis is the most serious disease in ayu cultivation, and infection from the microsporidian *Glugea* is also serious in some localities.

(*v*) *Yellowtail:* Bacterial tuberculosis (due to *Pasteurella piscida*), vibriosis, nocardial infection (*Nocardia kampachi*) and ectoparasitic trematode infection (*Benedenia seriola* and *Axine heterocera*) are principal epidemics in this fish. Nutritional disease in yellowtail cannot be neglected, because fish are fed on raw fish which sometimes lacks essential nutrients or contains rancid substances.

4 Estimation of loss through disease

It is important to make quantitative estimations of fish losses due to disease as a basis for establishing control measures. However, it is very difficult to obtain reliable figures. In 1973 and 1974, the Fisheries Agency tried to estimate the amount of damage caused by fish diseases. Questionnaires were distributed to 16 349 of Japan's 19 121 fish farms. Responses were obtained from 6 003 farms, 31% of the total number of fish farms. Based on the results of this investigation, the total loss caused by fish disease in 1973 was estimated as about 9 300 tons (Table II and Table III).

TABLE II
ESTIMATION OF PRODUCTION LOSS CAUSED BY FISH DISEASE IN JAPAN IN 1973

		Tons
Freshwater fishes		
Salmonids		1 143
Carp		403
Eel		2 340
Ayu		660
Coloured carp		626
Goldfish		170
Other fishes		446
	Total	5 788
Marine fishes		
Yellowtail		3 376
Sea bream		75
Penacid shrimp		66
Other fishes		26
	Total	3 543
	Grand Total	9 331

5 Occurrence of international fish diseases in Japan

The Government Consultation on an International Convention for the Control of the Spread of Major Communicable Fish Diseases convened by FAO in Aviemore, Scotland in 1974 approved a list of 10 fish diseases to be covered by certification requirements of the proposed convention (FAO, 1974). Six of these diseases occur in Japan; the other four have not yet been recorded (Table IV).

Infectious pancreatic necrosis (IPN), infectious haematopoietic necrosis (IHN), furunculosis, ulcer disease, gill necrosis and cestode infections are present in Japan. Viral haemorrhagic septicaemia (VHS), whirling disease (WD, caused by *Myxosoma* [*Lentospora*] *cerebralis*), spring viraemia (SV), and changes in the swim bladder, like 'swim bladder inflammation (SBI)' have not been recorded.

(*i*) *IPN:* Although a first outbreak of IPN was suspected in 1958, no attempt at virological isolation of the causative agent was made until 1971 (Sano, 1971). As shown in Table V, the disease spread year by year and was present in most prefectures by 1970.

(*ii*) *IHN:* The first outbreak of IHN in Japan was recorded in cultivated kokanee salmon (*Oncorhynchus nerka* var. *adonis*) in 1971 (Kimura and Awakura, 1972). In 1972, IHN virus was isolated from kokanee and sockeye salmon (*Oncorhynchus nerka*) in two hatcheries. At that time, eyed eggs of chinook salmon (*O. tshawytscha*) and sockeye salmon (*O. nerka*) had been introduced into these two hatcheries from the USA. It was suspected, therefore, that the disease entered Japan on these eggs. On the other hand, IHN virus had also been isolated from native sea-run trout fry in Toyama Prefecture in 1972 (Sano *et al*, 1974).

TABLE III
MAJOR FISH DISEASES RESPONSIBLE FOR LOSS OF PRODUCTION IN JAPAN, 1973

	%		%
Rainbow trout		*Goldfish*	
Vibriosis	27·4	Ulcer disease	82·3
Fungus disease	23·4	Anchor worm (*Lernaea*)	4·5
IPN	21·3	Kidney enlargement disease[b]	3·6
Bacterial gill disease	4·7	Red mouth disease[c]	2·0
Columnaris disease	3·6		
IHN	3·2	*Eel*	
		Branchionephritis	26·7
Native land-locked trouts		Columnaris disease	16·5
Columnaris disease	51·7	Red disease	13·1
Furunculosis	22·3	Red spot disease	11·8
Fungus disease	15·9	Fungus disease	5·2
Bacterial gill disease	4·3		
		Ayu	
Carp		Vibriosis	92·6
Ulcer disease	40·9	Red mouth disease[c]	0·7
Columnaris disease	34·9	Mycotic granulomatosis[d]	0·7
Bacterial slime disease	4·0	*Glugea* infection	0·6
Coloured carp		*Yellowtail*	
Ulcer disease	76·0	Bacterial tuberculosis	28·1
Epistylis infection[a]	7·1	Nocardial infection	9·5
White spot disease	4·2	Vibriosis	9·4
Columnaris disease	2·6	Ectoparasitic trematode infection	3·7

[a] *Epistylis longicorpora.* [b] *Mitraspora cyprinii.* [c] *Chondrococcus columnaris.* [d] *Saprolegnia* sp.

From this, it may be assumed that IHN virus occurred in the migrating salmonids.

The first Japanese outbreak of IHN in rainbow trout was found in two prefectures, Nagano and Shizuoka, in the autumn of 1972. By 1973, this disease had spread over six prefectures, and by 1974 over 15 prefectures.

TABLE IV
OCCURRENCE OF INTERNATIONAL FISH DISEASES IN JAPAN

	Present	*Not present*
Salmonidae	IPN IHN Furunculosis	VHS Whirling disease
Cyprinidae	Gill necrosis Ulcers Cestodes	SV Changes in the swim bladder

TABLE VI
INTERNATIONAL TRAFFIC IN LIVE FISH AND FISH EGGS IN JAPAN (KG PER ANNUM)

	Item	*1973*	*1974*
Exports	Goldfish	9 409	13 289
	Other fishes[a]	25 278	22 214
	Oyster seed	2 971 694	1 350 475
Imports	Aquarium fishes	48 048	37 380
	Eels	6 934 382	7 739 508
	Other fishes[b]	5 552 243	6 820 030
	Shrimp	80 909	188 367
	Elvers (as seedlings)	358 631	303 265
	Other fish seedlings	1 705	8 986
	Eyed fish eggs	1 017	903
	Brine shrimp (*Artemia*) eggs	7 446	6 017

[a] Mostly coloured carp
[b] Mostly marine fishes imported from the Republic of Korea
Source: Japanese customs clearance statistics

TABLE V
NUMBER OF PREFECTURES INSPECTED AND NUMBER OF OCCURRENCES OF IPN AND IHN IN RAINBOW TROUT, 1963–74

	IPN		*IHN*	
	Prefectures	Occurrences	Prefectures	Occurrences
1963	1	—	—	—
1964	1	—	—	—
1965	5	—	—	—
1966	8	—	—	—
1967	8	—	—	—
1968	9	—	—	—
1969	12	—	—	—
1970	7	40	—	—
1971	17	135	—	—
1972	15	112	2	—
1973	16	99	6	38
1974	17	74	15	—

Source: Annual conference of Japanese prefectural trout hatcheries

Many fishery workers believe that it is almost impossible to eradicate contagious agents, such as those of IHN and IPN, once they are present. Thus, public opinion in Japan is inclined to forbid the importation of live fish and fish eggs from areas where VHS or whirling disease are found.

(*iii*) *Furunculosis:* This disease is not harmful to rainbow trout. However, the native land-locked trout occasionally suffers heavy loss from this disease.

(*iv*) *Gill necrosis:* Gill necrosis is common in cultivated fishes. There are two kinds of gill necrosis: one is caused by *Chondrococcus columnaris*, another is caused by hypothermophilic myxobacteria. These two bacteria cause gill necrosis in salmonids, eel and cyprinids.

(*v*) *Cestodes:* Two kinds of cestodes have been recorded in fish in Japan, *Ligula intestinalis* and *Digramma alternans*, but their distribution is limited.

6 International traffic in live fish and fish eggs

Table VI shows the principal items of live fish and fish eggs exported and imported in Japan. The principal items of export are coloured carp, goldfish and oyster seed. The imported aquarium fish are mainly tropical. The eyed eggs are mostly salmonid. Elvers are imported from Europe, south Asia, and other areas. Importation of live eels and marine fish has been gradually increasing.

7 Control of fish diseases

In Japan, control of fish disease is not the concern of veterinarians but that of fishery workers. Prefectural fishery workers have directly accepted the task of diagnostic and consultative service to commercial hatcheries and fish farms. Information on serious fish diseases in each administrative district is accumulated at a designated prefectural station or national institute, and the measures or regulations for control are discussed at inter-prefectural or national-prefectural conferences. For viral diseases of salmonids, several prefectural inspection facilities allot a portion of their inspections to other prefectures. At present the inspecting network covers all of 47 administrative districts.

8 Certification and certifying officers

Although an inspection network has been established for salmonids, only infrequent inspections are made for other fish. At present, health certifications are not required to import live fish and fish eggs into Japan. However, in order to prevent the introduction of fish diseases, a national act is in preparation to regulate the transportation and importation of all forms of aquatic life from foreign countries. In this act, especially stringent provisions will be added to the international regulations for certain epizootics, such as VHS, whirling disease and channel catfish viral disease (CCVD).

For exportation of live and frozen salmonids to the United States, 33 officers have obtained approval as certifying officers by the USA Department of the Interior. These officers are also under obligation to inspect all salmonids which are exported. An inspection system for cyprinid fishes is being studied in the Fisheries Agency.

9 Research and training

In Japan, research on fish diseases is carried on in the universities, in national institutes under the Fisheries Agency and in prefectural fishery stations. At present, there are not enough fish pathologists and diagnosticians to meet the increasing demands for fish disease control.

Since 1973, the Fisheries Agency has implemented a programme to establish a fish disease control system. A number of specialists from universities and governmental and private institutes are engaged in this work. The programme includes three components: compilation of fish disease statistics; training of inspectors; and publication of a clinical guide book to fish diseases. The training programme is aimed at establishing about 120 officers in all prefectures and two volumes of the clinical guide book have been published.

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A Preliminary Report on Fish Diseases and their Control in Colombia

D. A. Conroy and C. Vásquez D.

Abstract

The diseases identified in coldwater and warmwater fishes, including ornamental species, in Colombia were primarily of bacterial, fungal and parasitic origins, and fish diseases were partially responsible for high fish mortalities in the economically important ornamental fish trade industry of the country. The absence of infectious pancreatic necrosis (IPN), infectious haematopoietic necrosis (IHN), viral haemorrhagic septicaemia (VHS), furunculosis (*Aeromonas salmonicida*) and whirling disease (*Myxosoma cerebralis*) in Colombia has also been established.

The Fish Pathology Service of Colombia is responsible for formulating recommendations and procedures for the control of fish diseases, and their basic policy in relation to fish disease control is to permit the use of only those products which have been tested and proved effective against diseases and for fish species under the environmental conditions existing in Colombia. In this respect, approved disease control products, such as Furanace and Parasan are being used effectively to reduce fish mortalities in the ornamental fish trade industry. The Service is also controlling the use of certain antibiotics and sulphonamides, and products of doubtful efficacy.

Rapport préliminaire sur les maladies des poissons et leur contrôle en Colombie

Résumé

Les maladies identifiées chez les poissons vivant dans les eaux froides et les eaux à température élevée de la Colombie, y compris les espèces ornementales, sont d'origines essentiellement bactérienne, cryptogamique et parasitaire et elles sont en partie responsables des fortes mortalités enregistrées dans le commerce des poissons ornamentaux que revêt une importance économique pour la pays. On a également établi que la Colombie est exempte de nécrose pancréatique infectieuse (NPI), nécrose hématopoiétique infectieuse (NHI), septicémie hémorragique virale (SHV), furonculose (*Aeromonas salmonicida*) et maladie du tournis (*Myxosoma cerebralis*).

Le Service d'ichtyopathologie de la Colombie est chargé de formuler des recommandations et d'établir des procédures pour la lutte contre les maladies des poissons; sa politique fondamentale en matière d'enrayement des maladies des poissons est d'autoriser uniquement l'utilisation de produits qui ont été expérimentés et se sont révélés efficaces vis-à-vis de maladies et d'espèces de poissons se développant dans les conditions d'environnement applicables à la Colombie. Sous ce rapport, certains produits agréés pour la lutte contre les maladies des poissons, tels que le Furanace et le Parasan, sont efficacement utilisés pour réduire les taux de mortalité dans le commerce des espèces ornementales. Le Service contrôle également l'utilisation de certains antibiotiques et sulphonamides, ainsi que celle des produits d'efficacité douteuse.

Informe provisional sobre las enfermedades de los peces en Colombia y su control

Extracto

Las enfermedades encontradas en Colombia en los peces de aguas frías y calientes incluidas las especies ornamentales, eran ante todo de tipo bacteriano, micótico o parasitario y a ellas se debía en parte el elevado índice de mortalidad de los peces que afectaba a la industria de peces ornamentales del país, de gran importancia económica. Se ha demostrado la ausencia total en Colombia de necrosis pancreática infectiva (NPI), necrosis hematopoyética infectiva (NHI), septicemia hemorrágica viral (SHV), forunculosis (*Aeromonas salmonicida*) y enfermedad del torneo (*Myxosoma cerebralis*).

El Servicio Ictiopatológico de Colombia se ocupa de formular recomendaciones y procedimientos para combatir las enfermedades de los peces. El principio fundamental por que se guía el control de las enfermedades ícticas es permitir solamente el empleo de aquellos productos que se han ensayado y han resultado eficaces para las enfermedades y especies en cuestión en aguas colombianas. Algunos productos aprobados, como Furanace y Parasan, se están utilizando con éxito para reducir la mortalidad de los peces en la industria de peces ornamentales. El Servicio controla además el empleo de algunos antibióticos y sulfonamidas y de varios productos de eficacia dudosa.

1 Introduction

One of the principal objectives of the FAO/UNDP Inland Water Fisheries Development Project in Colombia is to evaluate the future potential for aquaculture in the country. The rational exploitation and export of live ornamental fish also represents a commercial activity of considerable importance, and Colombia is currently the major country in Latin America in the ornamental fish export trade.

For these reasons, and taking into account the possible importance of fish diseases as a restraint to the successful development of aquaculture, the FAO/UNDP Project has commenced a programme of research on the major diseases of coldwater and warmwater fishes, including ornamental species, in Colombia. The data obtained will be utilized as a basis for recommending suitable measures for controlling these diseases.

The present document is a preliminary report on the main findings to date with respect to fish diseases in Colombia.

2 Coldwater species

The main species of interest among the coldwater fish is the rainbow trout (*Salmo gairdneri*), originally introduced into the country in 1939 and now widely distributed in Andean lakes and other water bodies in Colombia. Detailed studies have been made on the diseases affecting populations of rainbow trout (Conroy, 1975), and on the basis of these investigations it has been shown that infectious pancreatic necrosis (IPN), infectious haematopoietic necrosis (IHN), viral haemorrhagic septicaema (VHS), furunculosis (*Aeromonas salmonicida*), and whirling disease (*Myxosoma cerebralis*) are absent. The diseases which have been encountered in this species include bacterial haemorrhagic septicaemia (*Aeromonas* sp.), columnaris disease (*Flexibacter* [*Cytophaga*] *columnaris*), fin rot (mixed aetiology, but associated with the presence of myxobacteria), saprolegniasis (*Saprolegnia* sp.), nematodes in the musculature (*Eustrongyloides* sp.), and goitre.

With reference to native coldwater fish, the findings so far have shown that the species *Grundulus bogotensis* and *Eremophilus mutisii* are susceptible to ichthyophthiriasis (*Ichthyophthirius multifiliis*) and chilodoniasis (*Chilodonella* sp.) in the natural environment. It is of interest to record that rainbow trout in contact with *G. bogotensis* or *E. mutisii*, which were affected by ichthyophthiriasis or chilodoniasis showed no evidence of cross-infection with these protozoans. The presence of small numbers of nematodes and cestodes (? *Proteocephalus* sp.) in the gastrointestinal tract of *E. mutisii* in the Lake Tota region has also been recorded.

3 Warmwater species

Several cases of disease and parasitism have been detected in native species of warmwater fish in Colombia (Conroy and Vásquez, 1975). Ichthyophthiriasis has been diagnosed from the catfish species *Pimelodus grosskopfii* and *P. clarias*, as well as from *Prochilodus magdalenae* and from a number of small characins. Isolated cases of a 'boil disease' associated with the presence of the myxosporidian *Henneguya* sp. have also been observed in *P. grosskopfii* and *P. clarias*. Saprolegniasis constitutes a significant disease problem during the transportation of adult *P. clarias* from the natural environment to fish culture stations situated elsewhere in the country.

The main problems identified in warmwater fishes up to the present time are those associated with metazoan parasites. Monogenetic trematodes (*Dactylogyrus* sp.) have been observed affecting the gills of captive specimens of *Pimelodus grosskopfii*. Cases of 'black spot disease', due to digenetic trematode metacercariae in the skin, have been recorded for *Astyanax fasciatus*, *A. filiferus*, *Creagrutus magdalenae*, and *Prochilodus magdalenae* in the natural environment. Occurrence of nematodes in the gastro-intestinal tract and liver of fish is widespread in the natural environment, and they have been observed in specimens of *Brycon moorei*, *Cyrtocharax magdalenae*, *Hoplias malabaricus*, *Leporinus muyscorum*, *Mugil* spp., *Plagioscion surinamensis*, *Pseudoplatystoma fasciatum*, *Sorubim lima*, *Sternopygus macrurus*, and *Trachycorystes insignis*. An interesting observation made in the field is that both immature and mature male *Pseudoplatystoma fasciatum* from the River Cauca showed heavier nematode infestations than females of the same species. Leeches have been found occurring as ectoparasites on *Chaetostoma fischeri*, and the branchiuran crustacean *Argulus* sp. is a known parasite of *Brycon moorei*. Small numbers of *Prochilodus magdalenae* showing clinical signs of a tumour-like growth affecting the anal fin have been collected, and the etiology of this condition is being studied in greater detail.

4 Ornamental species

The principal disease problems observed in ornamental fish are those associated with poor handling and maintenance techniques. Cases of bacterial haemorrhagic septicaemia, columnaris disease, fin rot, tuberculosis, saprolegniasis, ichthyophthiriasis, chilodoniasis, oodiniasis, plistophorosis, infestations by monogenetic and digenetic trematodes, nematodoses, and ectoparasitic crustaceans are common in the holding facilities of ornamental fish exporters in Bogotá (Conroy, 1975; Vásquez, 1974).

Conservative estimates indicate that total mortalities due to all causes, including diseases, are in the region of 60% of all fish which enter the exporters' holding facilities in Bogotá from collection points widely distributed in different regions of the country. Fish diseases, therefore, constitute an important factor in the valuable ornamental fish trade in Colombia.

5 Fish disease control

The formulation of recommendations and procedures for the control of diseases of warmwater, coldwater and ornamental fish in Colombia is the exclusive responsibility of the Fish Pathology Service, set up and established within the framework of the FAO/UNDP Inland Water Fisheries Development Project.

The basic policy of the Service, in relation to fish disease control, is to permit the use of only those products which have been tested and proved effective for diseases and fish species under the environmental conditions applicable to Colombia. In this respect, much useful work has been undertaken on the control of diseases of trout, warmwater species suitable for aquaculture, and ornamental species of importance to the export trade.

On the basis of laboratory studies and field trials carried out by the Fish Pathology Service in close collaboration with INDERENA biologists throughout the country, the following commercial products have been approved and authorized for use: (*i*) Furanace 10% granules (Dianippon Pharmaceutical Co. Ltd., Osaka, Japan); (*ii*) Parasan, Myxosan, Povisan, Bactosan, Clorostat, Ficostat (Piscisan Hispánica Ltda, Barcelona, Spain); (*iii*) Masoten (Farbenfabriken Bayer GmbH, Leverkusen, Federal Republic of Germany).

Two examples will be given to illustrate the type of results which have been achieved by the Fish Pathology Service. Application of bathing in Furanace 10% granules, at a concentration of 0·05–0·1 ppm of nifurpirinol (as active ingredient), has led to a reduction in mortality of ornamental fish in Bogatá from 60 to 20%; it has been estimated that routine application of this control measure

would result in a saving to the Colombian ornamental fish export industry of at least US$258 300 per annum. The application of Parasan baths has similarly resulted in highly significant reductions in mortalities of a wide variety of warmwater fish species suitable for aquaculture, through control of diseases due to fungi and ectoparasitic protozoans and metazoans.

The results have demonstrated conclusively that the application of disease control procedures recommended by the Fish Pathology Service for Colombian species and for Colombian environmental conditions would be of considerable practical value and utility in combating and controlling the main types of infectious and contagious fish diseases detected in the country. At the same time, steps are being taken to prohibit the use of certain types of antibiotics, sulphonamides, *etc*, which are known to give rise to problems of resistance in bacterial fish pathogens and, in addition, to impose strict control on the use of products of doubtful efficacy for the control of diseases of ornamental fish, among others.

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The Feasibility of Combining Animal Husbandry with Fish Farming, with Special Reference to Duck and Pig Production

E. Woynarovich

Abstract

The benefits and techniques of duck, goose, chicken and pig production in combination with fish culture are reviewed. Mutual advantages are derived from joint culture of these domestic animals and fish, with benefits to fish production being obtained primarily through addition of organic fertilizer (manure).

In fish-cum-duck culture, efficient use is made of total biological production in a pond, and total protein production per unit area of water can be doubled. It is estimated that 4–6% of the duck manure added to a pond is converted into fish flesh, and 3–4% of the required digestible protein content of duck food can be obtained through foraging. Production of one-day-old ducklings and their care during the early stages (up to age 10–20 days) requires specialized knowledge and facilities. It is recommended that, for rapid expansion of fish-cum-duck culture programmes, duck breeding and distribution centres should be established.

Rearing of geese in combination with fish offers some economic benefits, but its further development is limited by low egg production of geese and their high mortality in the juvenile stage.

Repeated application of fresh pig and chicken manure to a pond (carbon manuring) maintains a high rate of primary productivity with approximately 3–5% of the manure applied being converted into fish flesh when used with carp monoculture. This conversion ratio could be higher in ponds stocked with plankton-feeding fish.

Possibilité de combiner la production animale, en particulier l'élevage des canards et des porcs, avec la pisciculture

Résumé

Les avantages qu'il y a à combiner l'elevage des canards, des oies, des poulets et des porcs avec la pisciculture sont examinés, ainsi que les techniques à utiliser à cet effet. Cette combinaison presente des avantages réciproques, les avantages pour la pisciculture résultant surtout de l'apport d'engrais organique (fumier).

En combinant la pisciculture et l'elevage des canards, on utilise efficacement la production biologique totale d'un etang et on peut doubler la production totale de proteines par unite de superficie d'eau. On estime que 4 à 6% des fientes de canard deposees dans un etang sont converties en chair de poisson et que les canards peuvent trouver dans l'étang 3 à 4% des protéines digestibles dont ils ont besoin dans leur ration. La production de canetons d'un jour et les soins à leur donner durant les premiers jours (jusqu'à l'âge de 10 à 20 jours) exigent des connaissances et des installations spécialisées. Il est recommande d'installer des centres de reproduction et de distribution des canards en vue de promouvoir l'expansion rapide des programmes d'elevage combine de poissons et de canards.

L'élevage combiné des oies et du poisson presente certains avantages economiques mais son developpement ultérieur est limite par la faible production d'oeufs des oies et par la forte mortalite des jeunes.

L'apport répété de déjections fraîches de porcs et de poulets dans un etang (fumure organique) maintient une forte productivite primaire, environ 3 à 5% de ces déjections étant converties en chair de poisson dans les étangs qui sont consacres uniquement à la carpiculture. Ce taux de conversion pourrait être plus élevé dans les étangs peuplés de poissons qui se nourrissent de plancton.

Posibilidad de combinar la cría de animales domésticos con la piscicultura, teniendo en cuenta especialmente la producción de patos y cerdos

Extracto

Se examinan los beneficios de la cría de patos, gansos, pollos y cerdos en combinación con la piscicultura, y las técnicas utilizadas para ello. La combinación de la cría de estos animales domésticos con la piscicultura permite obtener beneficios en ambos campos, que, en el caso de los peces, se deben ante todo a la adición de fertilizantes orgánicos (excrementos) a los estanques.

La combinación de la cría de patos con la piscicultura permite aprovechar eficazmente la producción biológica total de un estanque y hace posible duplicar la producción total de proteínas por unidad de superficie de agua. Se calcula que del 4 al 6% de los excrementos de patos que se arrojan a un estanque son transformados por los peces en carne propia y que los patos pueden obtener del 3 al 4% de la proteínas digeribles necesarias para su alimentación forrajeando directamente en el estanque. Para producir patitos de un dia y criarlos durante las primeras fases (hasta la edad de 10–20 días) son necesarios conocimientos e instalaciones especiales. Para lograr una rápida expansión de los programas de cría de patos con peces se recomienda el establecimiento de centros de reproducción y distribución de patos.

La cría de gansos combinada con la piscicultura permite obtener algunos beneficios económicos, pero su desarrollo se ve limitado por la escasa producción de huevos de los gansos y su elevada mortalidad en la fase juvenil.

La aplicación repetida de excrementos frescos de cerdos y pollos en un estanque (fertilización orgánica) permite mantener un elevado indice de producción primaria; en el caso del monocultivo de carpa, del 3 al 5% aproximadamente de los excrementos aplicados son transformados por los peces en carne. En estanques con peces que se alimentan de plancton pueden obtenerse índices de conversión aún más favorables.

1 Introduction

The cost of land and construction are the major capital investments in a fish farm. These costs are increasing throughout the world, and other costs such as those for fish feeds are also rising. It is imperative therefore, that fish (and other animal protein) production per unit area be increased to help offset such costs and help mitigate the world's 'protein-hunger' especially that of developing countries.

One such means to that end is a combination of some form of animal husbandry with fish farming. Of these forms, fish-cum-duck culture appears to be the most promising, but the use of other poultry or pigs in combination with fish culture may also serve this aim.

2 Fish-cum-duck culture

2.1 *History*

Ducks have been kept on fish ponds for centuries in Central Europe and China, although not on a commercial scale and without really considering the beneficial effect of the ducks on fish production.

Probst (1934) made the first scientific trials of keeping ducks on carp (*Cyprinus carpio*) ponds in Wielenbach, in the Federal Republic of Germany. He stressed the excellent effect of duck droppings on the natural fish food production of the pond. He found that every duck kept on a pond resulted in an increase in fish production of 0·9–1·7 kg. (This is rather high due to the poor productivity of the Wielenbach ponds.)

After the second world war food shortages—especially that of animal protein—and the trend toward intensive commercial fish culture initiated commercial-scale fish-cum-duck culture in Central European countries such as Czechoslovakia, the German Democratic Republic, Hungary and Poland. In these countries, practical fish culturists—through exchange of experiences—solved the techniques of maintaining a brood stock of ducks and rearing one-day-old ducklings, as well as rearing (nursing) 14–21-day-old (advanced) ducklings. These are both pre-requisites for fish-cum-duck culture on a commercial scale. Today millions of market ducks are produced yearly on fish ponds in these European countries, and the amount of duck meat produced significantly surpasses the production of fish. (Renner and Sarodnik, 1973; Balogh, Kozma and Mosonyi, 1975.)

Large-scale, profitable fish-cum-duck culture also exists in Taiwan Province of China (Ling, 1971), and FAO has assisted the introduction of fish-cum-duck culture in Nepal (FAO/UN, 1974).

2.2 *Biological and economic benefits of and prerequisites for fish-cum-duck culture*

A fish pond is a semi-closed biological unit from the biological production point of view. The pond provides not only space for fish but also their natural foods, oxygen for their respiration, and other requirements. Many other plants and animals also dwell in the pond. Some are harmful, some are innocuous, but many of them are by no means necessary for the process of fish flesh production. Monoculture of a fish species can never utilize all of the pond's biological resources. Such wastage means less fish production and a loss of profit. Conversely, the adoption of polyculture (the combined culture of two or more fish species) enables a more effective utilization of the resources of differing food niches in the pond. The addition of ducks to a fish pond now means that the space above the water column can also be used.

Thus, joint culture of ducks and fish on a commercial scale increases production of animal protein from the same unit area. Ducks searching for food in the shallow parts of the pond consume such organisms as frogs, tadpoles, mosquito and dragonfly larvae, molluscs, and aquatic weeds generally not eaten by commonly stocked pond fish. This decreases waste of natural food, and also eliminates a good many organisms which are harmful to cultivated fish.

It is true, of course, that ducks may eat some of the stocked fish. Generally speaking they must be kept off spawning and nursery ponds where the fish are smaller than 4 g. However, a healthy fingerling above 5–10 g can readily escape a duck so the problem is minimized (Balogh, Kozma and Mosonyi, 1975).

The major beneficial effect of the joint culture of fish and ducks derives from the fertilizing effect of the duck's droppings which raises the pond's biological production and thus increases fish food production. The realization of this effect depends on many factors, among them the basic productivity of the pond, stock density, and food habits of the stocked fish. Increases in fish crop are, therefore, quite variable. It has been calculated that one duck produces 6 kg of droppings during 30–40 days on a pond. It has been estimated that 100 kg of duck manure distributed continuously in pond water may result in an increase of 4–6 kg of fish flesh. Field experiments have shown that carp production increased by 100 kg on average by keeping 300 ducks on ponds in the second year of experiments in a farm in the German Democratic Republic (Blume, 1960). Under subtropical conditions the effect of duck droppings is even higher.

The average annual production of fish in a fish-cum-duck farm in Taiwan Province of China, where advanced techniques in fish and duck culture are applied, is about 3 500 kg/ha (Ling, 1971). Polyculture, repeated stocking, repeated selective harvesting and high density duck stocking (500–1 500/ha) are practised here. The duck droppings on such a farm are not only sufficient to produce a rich growth of natural fish food organisms, but part of the droppings is directly eaten by some of the fish. Some of the left-over duck feed when washed into the pond (especially if the feeding places are located in the pond) is also readily eaten by the fish. Ling (1971) states that the use of fertilizer and/or supplemental fish feed is therefore not necessary here, thus greatly reducing the costs of production.

With respect to the benefits to the ducks, a fish pond provides a clean and healthy environment for them, and pond-reared ducks are generally free from parasites and diseases. The natural pond foods eaten by the ducks are mostly protein-rich. The artificial feeds provided them can therefore be of lower quality, with about 13–14% digestible protein content. Ducks raised in crowded pens or yards need a feed of 16–18% (up to 20%) digestible protein content. Through rearing ducks on a fish pond, 200–300 g of digestible protein per duck can be saved (*ie*, equivalent to 2–3% of its food). It should be noted that if pelleted feeds are used the feed coefficient will be better if the ducks are kept in pens (dry keeping). In this latter type of culture, about 2·9–3·2 kg of feed provides 1 kg of duck meat. Such a feed conversion rate cannot yet be achieved in fish ponds because ducks move freely there—using more feed for maintenance. In ponds, it requires about 3·3–3·5 kg of feed to produce 1 kg of live-weight duck.

The complexity of pond interactions and the effects of man's interventions make it very difficult to measure with great accuracy the mutually beneficial effects of ducks and fish. Nevertheless, practical trials support the practice, and experience of the last 15 years (Balogh, Kozma and Mosonyi, 1975) has shown that by combining fish and duck culture the production of both animals increases and their costs of production decrease. The quality of the pond-reared duck is superior to that of the pen-reared one. Due to the higher protein-rich natural food the fish are healthier, their flesh is not as fat, and their feed conversion rate is better (only 1·8–2·2 kg value feed is necessary to produce 1 kg of carp in Hungary). The pond-reared ducks also

produce excellent clean feathers, which are worth 13–15% of the value of their meat.

The capital investment in a duck pen-rearing system is higher than in the case of pond-rearing. Pen-rearing has many problems with elimination of faecal wastes, which usually pollute the recipient river and create offensive odours.

Pond-reared duck farming also requires less capital investment than intensive chicken farming, and due to the short growing (production) time of 48–52 days, or under less intensive conditions 55–65 days, the return on the costs of investment and production is rapid.

Joint culture of fish and ducks permits more efficient utilization of man power, transport equipment and storage facilities. For example, the same pelleting and feed preparation machines can be used for processing fish and duck feeds.

The prerequisites for development and extension of fish-cum-duck culture are as follows: (*i*) Subsidy of capital investments (70% subsidy was necessary in Hungary). (*ii*) Profitable market prices. (*iii*) Extended marketing possibilities, such as development of a processing industry which kills, cleans, packs and stores the duck meat, utilizes the feathers and offal, *etc.* (*iv*) Highly productive, well adapted duck strains or hybrids. (*v*) Presence of an animal feed industry or facilities and ingredients to produce mixed pellet feeds. (*vi*) Adequate equipment (*eg*, incubators), and technical facilities. (*vii*) Trained personnel for all levels of production.

2.3 *Practical aspects of fish-cum-duck culture*

The practical aspects of duck culture (which determine the success of fish-cum-duck culture) can only be outlined in the review which follows. Unfortunately, the most cited manual on the subject (Balogh, Kozma and Mosonyi, 1975) is available only in Hungarian.

2.3.1 *Characteristics of the Peking duck.* Both meat- and egg-producing ducks can be reared on ponds. In Central Europe, a fast growing meat duck (Peking duck and hybrids of that strain) is cultured. Some characteristics of the Peking duck follow:

Brood ducks. Weight: females, 3·2–3·5 kg: males 3·4–4·0 kg. They are stocked in a ratio of 1 male to 4–6 females. The age of the brood is 1–4 years. The brood stock is usually sorted out after the first egg-laying season. Sexual maturation is achieved at 5 months, and egg-laying commences at 6–7 months. The number of eggs produced annually per duck is 120–130. A normal egg weighs 80–90 g and is 8 cm long and 5 cm wide. A brood duck can incubate 12–15 eggs. A brood hen can hatch 10–15 duck eggs. The incubation time is 28 days. Hatching starts on the 25th or 26th day. In Hungary, the number of market ducks raised from one brood (female + male) is over 60 per year.

Market ducks. The growing period is 48–52 days. It takes 7–8 weeks after hatching to reach the marketable size of 2·3–2·5 kg live weight. Each duck produces 150 g of marketable (usable) feathers. The quantity of droppings per duck is 6 kg. In general 3·2–3·5 kg of feed mixture is converted to 1 kg live weight. The average loss of weight when the duck is killed is 15–17% (blood, 3–4%, feathers 4–5%, gut, 5–8%, evaporation 1%).

The meat type of Peking duck is a voracious fast growing animal. It is not advisable to keep it more than 7–8 weeks because it then starts to moult; this is undesirable for processing and its growth practically stops. It is easy to train a Peking duck to remain in a given pond, rest overnight in the same place, and come for feed at the same time of day. A duckling which survives its early age (14–20 days in Europe and 10–14 days in the tropics and sub-tropics) is a very hardy animal. Under poor conditions, however, its production (growth, utilization of feed, egg production, number of fertilized eggs, hatching ratio, *etc*) suffers.

2.3.2 *Production of one-day-old ducklings.* The production of ducklings is, of course, dependent upon the maintenance of an adequate brood stock of a selected strain (one male to 4–6 females). During one laying season under good conditions, a Peking duck will lay 120–160 eggs (the record is 250 eggs). During peak production, two eggs are laid every three days. One female duck will produce 70–80 one-day-old ducklings during a laying period of 8 months under suitable conditions of brood keeping and hatching. During the laying season the females require a protein-rich feed (16–18% digestible protein, calcium carbonate and other minerals) and a round-the-clock adequate supply of clean drinking water, a decisive factor for successful egg laying. In order to produce one egg, 0·42–0·52 kg of feed is needed (this includes the feed for the males as well) during the 8 month long season. One brood duck consumes 40–45 kg of feed from its first day after hatching up to the time when egg laying starts. Egg laying suffers under crowded conditions. One brood duck needs: 1–1·5 m^2 of dry run (yard area), 1–1·5 m^2 of water run (pond area) and 0·3–0·5 m^2 of pen area. During the egg laying period the brood stock has to be kept in a well protected fenced area to ensure economical feeding and avoid egg losses.

Egg laying is stimulated by light, and can be promoted and regulated through artificial illumination. Two watts of light (preferably yellow) are required for 1 m^2 of area.

2.3.3 *Nursing very young ducklings*

2.3.3.1 Nursing one-week-old ducklings. During its first week of life, a duckling is a very sensitive animal, more sensitive than a chick of the same age. To avoid heavy losses, the following requirements must be met:

(*i*) *Temperature:* 31–29°C, up to the third day; from 4–7 days a temperature of 26–23°C. Artificial heating is necessary even in sub-tropical areas. The pen must be well ventilated: a change of 0·05–0·06 m^3 of air per minute per duckling.

(*ii*) *Space:* About 1 m^2 of pen area is required for 25–28 early ducklings. After they are three days old they can be kept in the open when it is warm enough.

(*iii*) *Light:* If the pen is illuminated, the duckling eats round the clock and consequently grows faster.

(*iv*) *Food:* A special feed is used, preferably 3 mm pellets of 18–19% digestible protein, minerals and vitamins, offered in simple self-feeders.

(*v*) *Drinking water:* Clean running water is a necessity, but one must prevent the ducklings from splashing in it.

(*vi*) *Splashing place:* From 4–5 days of age the duckling has to be gradually habituated to water. Clean, warm, shallow water has to be provided; dirty water (thickened from feed residues) hinders the duckling's progress.

(*vii*) *Cleanliness:* The duckling suffers if its resting place is wet or dirty from droppings. In a modern nursery, ducklings are kept in a heated pen on a metal screen (1·5 cm

mesh) about 1 m above a floor where the droppings fall. Heating (warm air circulation) is from below. About 50–55 one-day-old ducklings can be kept here up to the 5–7 day-age.

2.3.3.2 Rearing advanced ducklings. In its second week the duckling has to be stocked in a small pond after gradual adaptation to life on the water. Small specially installed rearing ponds are used for this purpose. The duckling needs shelter from bad weather or rain, and protection from enemies. No essential change is needed in food and feeding. If nursing and rearing of the early ducklings is adequate, their mortality is only 2–4%.

2.3.4 *Rearing market ducks on a fish pond.* Water-habituated, advanced ducklings are hardy enough to stock in ponds. The flocks usually keep together, making their care fairly simple.

To serve their main aim for fish culture, that is that their droppings reach the pond water, fixed (not floating) resting and feeding places are constructed above the water surface. When the flock rests and eats on the shore or on earthen islets about half of the droppings fall on dry land unavailable to the biology of the pond. Their feed wastage is also unavailable to the pond/fish metabolism.

2.3.5 *Feed, growth and conversion rate.* Rapid growth of ducks requires qualitatively and quantitatively suitable feeds preferably in the form of dry pellets. Four types of feed mixtures are used: (*i*) a starting feed, for early ducklings; (*ii*) a rearing feed; (*iii*) a fattening feed, used the last 10 days before marketing; and (*iv*) a layer's feed, used before and during the egg-laying period.

The following percentages of digestible protein are required in these feeds: 17–18% up to three weeks of age; 14–15% at 6 weeks; 10·5–12% at 7–8 weeks.

The composition of these feed mixtures is shown in Tables I–III. For amount of feed required, see Table IV.

TABLE I
THE COMPOSITION OF FEEDS USED TO PRODUCE MARKET DUCKS

Components	*Starter*	*Rearing*	*Fattening*	*Layer's*
Dry matter	86	86	86	86
Starch value	68	68	69	67
Protein, digestible	18	15	11·5	16–18
Protein, crude	20·5	18	14	19–20
Food lime	3	3	3	4·5
Food phosphate	0·8	0·7	0·7	1·6
Vitamin-premix	0·5	0·5	0·5	0·5
Mineral-premix	0·5	0·5	0·5	0·5

TABLE II
COMPOSITION OF 1 000 g VITAMIN PREMIX

Ingredient	*Unit*	*Quantity*
Vitamin A	Int. unit	2 000 000
Vitamin D_3	Int. unit	400 000
Vitamin E	Int. unit	2 000
Vitamin K_3	mg	400
Vitamin B_1	mg	400
Vitamin B_2	mg	800
Vitamin B_5	mg	1 000
Vitamin B_6	mg	400
Vitamin B_{12}	mg	4
Niacin	mg	4 000
Choline	mg	160 000
Etoxy-methyl-kinolin	mg	25 000
Bran flour	up to g	1 000

TABLE III
COMPOSITION OF 1 000 g MINERAL PREMIX

Ingredient	*Unit*	*Quantity*
Potassium phosphate	g	600
Monocalcium phosphate	g	300
Manganese	mg	15 000
Iron	mg	1 000
Zinc	mg	6 500
Copper	mg	300
Iodine	mg	120
Food lime	up to g	1 000

The most important feed ingredients are maize, barley, wheat, wheat bran, rice bran, soybean flour, oil seed cakes (except mustard and peanut oil cake), yeast, fishmeal, meatmeal, feed fat, or similar local products. The crude fibre content mixture cannot exceed 6–7% without deterioration of the feed's digestibility (Nehring and Knabe, 1961).

TABLE IV
AMOUNT OF FEED (IN KG) REQUIRED BY 100 DUCKS

Week	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*
Daily needs	3	5·5	11·5	18	21	25	26	25
Amount fed per week	21	38	80	126	147	175	182	175

It is advisable (or even a requisite) to offer the feed in self-feeders, where the animals can eat round the clock.

TABLE V
GROWTH OF PEKING DUCK

Age	*Weight (g)*		
	Good growth	*Medium growth*	*Poor growth*
Day 1	50–60	50	40
Week 1	180	170	125
Week 2	380	250	210
Week 3	750	500	350
Week 4	1 200	800	530
Week 5	1 600	1 200	645
Week 6	2 000	1 500	950
Week 7	2 350	1 800	1 200
Week 8	2 500	2 000	1 500

The growth of Peking duck from one-day-old duckling to an 8 week market duck is shown in Table V above.

The conversion rate of an adequate feed mixture differs for each growing stage as shown on Table VI. It becomes less efficient as the duck grows older.

TABLE VI
FOOD CONVERSION IN MARKET DUCKS

Age (days)	*Weight (g)*	*Feed necessary to produce 1 kg live weight (kg)*
1	50–60	—
7	180	1·55
14	370	2·25
21	710	2·50
28	1 070	2·75
35	1 560	3·21
42	2 020	3·85
49	2 400	4·40
52	2 510	6·30

2.4 *Economic questions*

The capital investment for fish-cum-duck culture differs from place to place, and is rather high especially if production of one-day ducklings and their subsequent nursing is

considered. A well operated breeding and duckling distributing centre is in fact a basic requirement in developing countries.

The production costs of the market duck depend on many factors: growing time, availability and costs of feeds (especially ones rich in protein), mortality rates, caring costs, transport, market facilities, *etc.*[1] The storing and preparation of feeds, transport and overseeing costs are partly shared with the cost of fish culture. Finally the market price for the ducks is a decisive factor in deciding upon extension of this type of culture.

Just as it is difficult to measure accurately the exact beneficial effects of ducks on the fish crop (section 2.2) it is also a complex task to measure the profitability of fish-cum-duck culture in all instances. Examples from Central Europe and the Far East show that this system of increasing animal protein production can be profitable and a considerable contribution in filling the protein gap.

3 Fish-cum-goose culture

Fish-cum-goose culture was initiated in Central Europe following the experience of successful fish-cum-duck culture. Its extent is rather limited. In 1972 56·7 tons were produced in the German Democratic Republic, and 55·0 tons produced in Hungary.

The fast growing meat type of European goose attains marketable size (4·3–4·5 kg) in 50 days. Its protein need is lower than that of ducks and chickens, and it eats green fodder. The feed conversion rate of geese is better than that of ducks, chickens or turkeys. In raising geese on fish ponds, where grazing is possible along the shore, 1·9–2·8 kg of feed is necessary for a 1 kg increase in live weight (Bögre, 1968).

Goose flesh is excellent, tasty and well flavoured; the liver is highly valued as are its feathers.

Adequately weather-acclimated and water-habituated young geese are stocked in a pond when 20 days old. (A goose's weight at this age is 1 500 g.) A goose remains in the water for a shorter time than a duck, likes to rest on the shore and graze around the pond. The beneficial effect of goose raising on a pond is far lower than that of ducks.

Extension of fish-cum-goose culture is hindered by low egg production (30–60 eggs per year) and high juvenile mortality. There is a need for more experimental work on this type of culture, including selection of more suitable strains and improvement of those in use.

4 Poultry and pig production

Raising poultry (chickens) and fattening pigs in combination with aquaculture demonstrates another aspect of joint culture in which manure is also used to increase fish production.

4.1 *Biological basis of manure utilization*

Using animal manure (*eg*, pig, sheep or poultry) in fish ponds is an age-old practice in Europe. Originally two heaps or 0·7–0·8 tons of manure per ha was placed in a pond when it was filled, or manure was spread over the dry pond bottom at the rate of 1–2 tons/ha. The manure decomposed and consumed oxygen, while methane, hydrogen sulphide, and ammonia developed. There was danger of general or local oxygen deficiency and consequent fish kill, and the use of manure on the pond bottom was beneficial only to ponds with very poor soil and low productivity. Even there, the crop increasing effect of the manure was poor, only about 1–2 kg fish per 100 kg of manure.

In an endeavour to utilize pig manure more effectively (it was not used by farmers and was a pollutant at commercial piggeries), a 'carbon-manuring technique' was worked out in Hungary in 1952–53 (Woynárovich, 1956, 1956a, 1956b). The basis of this technique is that when soft fresh manure is mixed with pond water and repeatedly spread over the entire surface of the pond, carbon compounds are released which lead to a continuous high primary production.

When ducks distribute their droppings in a pond they are living 'carbon-manuring machines'. Poultry droppings or pig manure has to be distributed continually at very short intervals preferably in a fresh condition because its carbon content is highest at this stage (some farms in Hungary distribute the manure five times a week). Using the carbon-manuring technique, very large quantities of manure can be spread in a pond (30–60 tons/ha/100 days). This also avoids environmental pollution. The pond water receives well distributed manure without any trace of odour and converts it, through the natural food chain, into fish flesh.

4.2 *Chemical composition of manures used in fish culture*

TABLE VII
COMPOSITION OF 100 kg MANURE (HUNGARIAN DATA)

Components	*Pig manure (fresh)*	*Chicken droppings*	*Duck droppings*	*Goose droppings*
Water	71	56	57	77
Organic matter	25	26	26	14
Nitrogen	0·5	1·6	1·0	0·6
P_2O_5	0·4	1·5	1·4	0·5
Potassium (K_2O)	0·3	0·9	0·6	1·0
Calcium	0·09	2·4	1·8	0·9
Others	0·9	3·5	2·8	1·4

A fat pig produces 1·6–1·8 tons of manure (including urine) per year on the average. This means that the fresh manure of 15–25 pigs can be used in a 1 ha pond.

4.3 *Use of the carbon-manuring techniques*

In order to save transport costs it is advisable to position poultry pens or pig sties near the ponds where the manure will be used. If dry, the manure must be softened and the soft manure is dispensed from a manuring boat. If the boat is driven by an outboard motor, the manure is shovelled into a basket made of iron rods (2–2·5 cm apart) suspended from the boat so that it sinks to a depth of about 10–20 cm. As the boat moves forward, the turbulent currents wash out, dilute, and dispense the manure over the pond.

Another method (one originally used in 1952–56) is to use a pump built into the boat bottom. The manure is shovelled into a hopper where it is diluted with pumped water and sprayed out into the pond through a hose equipped with an end plate which fans out the mixture.

In small ponds, where the use of machines is not practicable, the manure can be diluted and distributed by hand from the shore or from a small boat.

As both poultry and pigs are raised in separate closed systems, there is no danger of introducing parasites into the ponds.

[1] It should be noted that during the last ten years the duck growing time in Central Europe has been decreased from 70–75 to only 48 days.

4.4 *Economic considerations*

The technology of poultry farming and pig fattening is already well developed. The capital investment and production costs are well known or can be calculated from basic data. The major advantages of joint culture of fish and pigs or poultry lie in finding a solution to the problem of manure disposal coupled with gaining an increase in fish production. In addition, operational efficiency of the farm is gained through better use of man-power, and joint use of feed storing, processing and transport facilities when fish culture and pig or poultry farming are combined.

Experience has shown that in the case of common carp (*Cyprinus carpio*) monoculture, 3–5 kg of carp can be produced by using 100 kg of pig manure. In ponds where plankton-feeding fish, such as silver carp (*Hypophthalmichthys molitrix*) and bighead (*Aristichthys nobilis*), are stocked, the utilization of manure is far higher, and the 'water-bloom' of blue-green algae can be avoided. In applying the carbon-manuring technique in Hungary, where the production period is only 150 days, a natural yield was achieved of 500–800 kg/ha.

As in the use of ducks or geese to fertilize fish ponds, exact analysis of the beneficial effects on the fish crop is difficult, due to the complexity of the processes involved, but the contribution is believed to be significant.

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Aquaculture en Rizières: Situation et Rôle Futur

M. M. J. Vincke

Résumé

La rizipisciculture est une utilisation plus rationnelle d'un milieu aquatique existant, c'est la mise en valeur complémentaire de la rizière irriguée. En général, la hauteur de l'eau dans une rizière est assez faible (5–25 cm) et le fond de la rizière est très fertile, ce qui entraine le développement de zoo- et phytoplankton. Cette richesse peut être pleinement utilisée grâce au poisson qui transforme en chair comestible ce que le riz n'utilise pas. Le riz étant l'objectif principal il faut adapter l'élevage du poisson aux exigences culturales du riz. Avant tout il est indispensable d'avoir la maîtrise de l'eau et d'aménager dans les rizières un drain et un ou plusieurs trous-refuges où le poisson se réfugie quand l'eau baisse.

Les espèces de poissons utilisées doivent pouvoir vivre en eau peu profonde, supporter des températures élevées et de faibles teneurs en oxygène dissous, avoir une croissance rapide, résister à la turbidité de l'eau et être sédentaires. Les espèces les plus utilisées dans le monde sont: *Cyprinus carpio, Tilapia mossambica, Trichogaster pectoralis, Ophiocephalus striatus* et *Clarias batrachus*. D'autres espèces, notamment des malacophages, peuvent présenter toutes les qualités requises, mais n'ont pas encore été testées systématiquement en rizière. La rizière constitue un ensemble de plusieurs niches écologiques différentes. En associant des espèces à régime alimentaire différent on exploite plus efficacement ce milieu. Des crustacés peuvent aussi être associés aux poissons.

Les pratiques culturales modernes du riz impliquent l'emploi d'engrais chimiques, de produits phytosanitaires et d'insecticides dont les effets toxiques sur le poisson constituent de sérieux obstacles. Dans les rizières aménagées et cultivées correctement et où il y a complète maîtrise de l'eau les dégâts causés par les poissons sont négligeables. Au contraire, les poissons peuvent beaucoup aider à la lutte contre les végétaux adventices, les mollusques et les moustiques grâce à un choix judicieux d'espèces herbivores, malacophages ou larvivores.

La revue de la rizipisciculture dans le monde permet d'en dégager les tendances actuelles. La pratique de la rizipisciculture ne doit pas être considérée seulement comme source de revenus mais surtout comme un moyen d'assurer la fourniture de protéines animales dans des régions où elles font défaut.

Rice paddy aquaculture: its situation and future role

Abstract

Fish culture in rice paddies is one of the best ways of using available aquatic resources in that additional protein production is obtained from lowland (irrigated) rice areas. As a rule, the water in rice paddies reaches a level of 5–25 cm. As the paddy bottom is highly fertile, the production of zoo- and phytoplankton is high. These resources can be fully utilized by fish, thus converting into edible food what rice plants do not utilize. Since rice remains the main crop, fish culture has to be adapted to its requirements. Firstly, it is essential to have complete control over the water and to provide drainage outlets in the paddies. Secondly, one or more refuges must be made for the fish when the water level is lowered.

The species of fish to be used must be able to survive in shallow water, and to endure high water temperatures and low dissolved oxygen content. Fish species should also be sedentary, have rapid growth and be able to withstand turbid water. The species most commonly cultured throughout the world in combination with rice are: *Cyprinus carpio, Tilapia mossambica, Trichogaster pectoralis, Ophiocephalus striatus*, and *Clarias batrachus*. Other species, in particular the malacophagous species, which may have the required characteristics, have yet to be tested systematically in rice paddies. In fact, rice paddies consist of several different ecological environments, and by raising species with different diets in association with one another, this environment can be exploited to the fullest. It is also possible to raise shellfish along with finfish.

Modern rice-growing techniques call for the use of chemical fertilizers, plant protection products and insecticides, and their toxic effects on fish may present serious obstacles to fish culture in paddies. In paddies where full control is exercised over water and which are correctly managed and stocked for fish culture, fish cause little harm. In fact fish can be highly beneficial in eliminating weeds, molluscs and mosquitoes if a wise choice is made of herbivorous, malacophagous or larvivorous species.

This world review of rice-cum-fish culture reveals current trends. Not only can the practice of fish culture in rice paddies be considered a source of income, but it is especially a means of supplying animal proteins in areas suffering from protein shortages.

Acuicultura en arrozales: situación y función futura

Extracto

La piscicultura en arrozales representa una forma de utilizar más racionalmente un medio acuático ya existente, aprovechándolo para otros fines. En general, la altura del agua en los arrozales es poca (5–25 cm) y el fondo muy fértil, lo que determina la formación de zooplancton y fitoplancton. Esa riqueza puede aprovecharse plenamente gracias a los peces, que transforman en alimento comestible lo que el arroz no utiliza. Dado que la producción de arroz es el objetivo principal, la piscicultura ha de adecuarse a las exigencias de cultivo de ese producto. Ante todo, es indispensable poder regular las aguas y contar con un sistema de drenaje y uno o varios refugios donde los peces puedan retirarse cuando el nivel del agua desciende.

Las especies de peces que se utilizan deben poder vivir en agua poco

profunda, tolerar temperaturas elevadas y un bajo contenido en oxígeno disuelto, crecer rapidamente, resistir a la turbidez del agua y ser sedentarias. Las especies más utilizadas en combinación con arroz en el mundo son: *Cyprinus carpio, Tilapia mossambica, Trichogaster pectoralis, Ophiocephalus striatus* y *Clarias batrachus*. También otras especies, sobre todo malacófagas, pueden reunir todos los requisitos necesarios, pero todavía no se ha ensayado sistemáticamente su cultivo en arrozales. Los arrozales son un conjunto de varios nichos ecológicos distintos, por lo que criando en ellos especies de régimen alimentario diferente se pueden explotar más eficazmente. Es posible también asociar la cría de crustáceos a la de peces.

Los sistemas modernos de cultivo del arroz entrañan empleo de abonos químicos, productos fitosanitarios e insecticidas, cuyos efectos tóxicos en los peces podrían constituir obstáculos serios para la piscicultura. En los arrozales estructurados y cultivados adecuadamente y donde el agua está plenamente regulada, los daños a los peces son insignificantes. Más aún, los peces pueden ser muy útiles para combatir las plantas adventicias, moluscos y mosquitos, si es que se eligen adecuadamente especies herbívoras, malacófagas o insectívoras.

Este examen de la situación actual de la piscicultura en arrozales en todo el mundo revela las tendencias actuales. La piscicultura en arrozales no debe considerarse solamente como una fuente de ingresos, sino, sobre todo, como un medio de asegurar el abastecimiento de proteínas animales en regiones que sufren de escasez de proteínas.

1 Introduction

Utiliser l'eau des rizières irriguées pour y élever des animaux aquatiques est un moyen d'augmenter la production de protéines animales dans le monde. La pisciculture en rizières est la plus développée dans la région Indo-Pacifique et elle existait en Inde il y a plus de mille cinq cents ans. De l'Inde, cette technique d'utilisation des rizières a été introduite dans le Sud-Est asiatique, depuis plus d'un siècle. Vers 1900, elle a été mise en pratique à Madagascar. A la fin du 19ème siècle, la rizipisciculture s'est développée en Italie et elle a débuté aux Etats-Unis.

Au cours des années, divers auteurs ont fait le point du développement de ces techniques dans les différentes parties du monde. En 1957, sur la base des publications disponibles, la Division des Pêches de la FAO avait rassemblé des renseignements concernant la rizipisciculture dans 25 pays du monde (FAO, 1958). En 1966, à l'occasion du Symposium Mondial organisé par la FAO sur la pisciculture en étang à température élevée, un certain nombre d'auteurs ont donné des informations intéressantes à ce sujet. Coche (1967) a présenté une excellente synthèse de la rizipisciculture telle qu'elle se pratiquait, à l'époque, dans 29 pays du globe. Huet (1970) a également fait le point du développement de la pisciculture en rizière dans les diverses parties du monde. Enfin, la situation actuelle de la rizipisciculture en Afrique a été décrite par Vincke (1976). Le but de la présente note est de faire le point de la situation de l'aquaculture en rizières dans le monde, passer en revue les réalisations dans ce domaine et décrire les techniques utilisées jusqu'à présent.

Dans beaucoup de pays existent des possibilités, parfois considérables, de développer la riziculture irriguée et la rizipisciculture avec des chances de succès. Il y a lieu de rappeler ici que, selon le rapport (1967) sur le problème alimentaire du 'President's Science Advisory Committee' des Etats-Unis cité par Pillay (1973), il a été estimé que si l'on utilisait seulement 30% des 35,6 millions d'hectares de rizières irriguées existantes pour y faire de la rizipisciculture, l'on pourrait, même avec des rendements assez bas, obtenir approximativement 2,2 millions de tonnes de poissons.

2 Les méthodes de production de poissons en rizières

2.1 *Intérêt de la rizipisciculture*

Les rizières irriguées ont des plans d'eau peu profonds dans lesquels il est possible d'élever du poisson. Dans pratiquement tous les continents où elles existent, les paysans ont essayé d'augmenter leurs revenus en élevant des poissons en rizières.

La rizipisciculture est une des meilleures utilisations des terres (Coche, 1967). Le poisson élevé en rizières aménagées, où il y a la maîtrise de l'eau, n'est absolument pas un concurrent pour le riz, bien au contraire. Pendant une partie de l'année, les rizières offrent aux poissons un milieu riche, aussi bien durant le cycle de croissance du riz qu'après la récolte du paddy, si toutefois la parcelle reste inondée.

L'élevage de poisson en rizières peut donc être pour le paysan: (*i*) un supplément appréciable de son revenu monétaire. Dans certains pays, notamment à Madagascar, le produit de la vente du poisson paie tous les travaux de culture du riz (labour, repiquage, sarclage et moisson). (*ii*) une source non négligeable de protéines animales: les rizières, par la richesse de leur faune (insectes, larves, têtards, zooplancton) et de leur flore (algues et phytoplancton), constituent un excellent milieu d'élevage pour les poissons, surtout si le paysan applique une bonne fumure. (*iii*) une amélioration des conditions de culture du riz par une diminution des insectes nuisibles et par réduction des travaux d'entretien, notamment quand on utilise des espèces phytophages. (*iv*) une amélioration des conditions sanitaires dans les rizières: les poissons contribuent au contrôle des mollusques et des moustiques, vecteurs de la bilharziose et de la malaria.

Même si dans quelques cas elle présente certains inconvénients, la rizipisciculture n'est en somme que l'utilisation plus rationnelle d'un milieu aquatique existant. C'est une mise en valeur complémentaire de la rizière irriguée.

2.2 *Conditions écologiques des rizières*

Par rapport à l'étang de pisciculture, la rizière irriguée est un milieu aquatique spécial caractérisé par: (*a*) la profondeur assez faible (en général 5 à 25 cm) du plan d'eau que constitue la rizière irriguée, du moins là où il y a la maîtrise de l'eau. (*b*) la fertilité élevée des rizières. Leur sol, du moins dans les bas-fonds, est généralement constitué de terres marécageuses assez fertiles. Elles ont naturellement un pH acide, mais la majorité des paysans applique une fumure qui corrige ces carences. On peut dire que, bien souvent, le fond des rizières, du fait des soins culturaux (labour, assec annuel, engrais et fumier), est plus fertile que bon nombre d'étangs de pisciculture où les travaux d'entretien et d'amélioration indispensables ne sont pas toujours effectuées. L'eau des rizières est donc généralement mieux pourvue en éléments minéraux que l'eau de nombreux étangs de pisciculture. (*c*) un développement, plus important qu'en étangs, de la faune et de la flore des rizières, du fait du taux relativement élevé de certains éléments minéraux résultant de la fertilisation. On constate que dans les rizières fumées convenablement (fumier de ferme et engrais minéraux), certains éléments du zooplancton se développent mieux qu'en étangs (par exemple Cladocères et Copépodes). (*d*) le phytoplancton semble également plus riche en rizière qu'en étang. On rencontre couramment de nombreuses espèces de Chlorophycées (Desmidiées et Chlorococcales), des Cyanophycées (*Microcystis* et *Anabaena*) et des Bacillariophycées.

Il y a lieu également de se souvenir, comme le rappelle Lemasson (1955) qu'en région tropicale, on trouve dans les rizières des quantités considérables de larves de diptères et

spécialement de chironomes. Ces larves occupent le niveau superficiel du sol de la rizière et on en compte souvent plus de 10 au cm^2. Elles se nourrissent de matières végétales et jouent un rôle important dans la désintégration rapide de la paille de paddy enfouie dans la rizière. Les matières azotees de ces larves sont perdues pour la consommation humaine et pour le cycle nutritif de la rizière si elles se transforment en insectes parfaits. Or, les carpes en font une grande consommation, les transformant ainsi en aliments utilisables par l'homme.

Lemasson (1955) signale également le développement des algues qui absorbent beaucoup d'éléments nutritifs et forment une couche qui fait écran à la lumière. Or les *Tilapia* (*T. mossambica* et *T. rendalli*) et le sepat siam (*Trichogaster pectoralis*) mangent ces algues. Dans les 24 heures qui suivent leur introduction, une partie des éléments nutritifs qu'elles contenaient est remise à la disposition du riz, les excréments des poissons étant rapidement recyclés par l'action des enzymes et bactéries.

L'un des principaux inconvénients de la rizière pour le poisson est la faible profondeur du plan d'eau et le fait qu'il n'y ait pas toujours de l'eau courante.

On peut donc admettre que la rizière irriguée est un milieu au sein duquel se développe une chaîne alimentaire que le riz seul ne peut valoriser complètement. Le poisson, surtout en polyculture, constitue dans ce cas un complément positif.

2.3 *Modalités d'adaptation des méthodes de rizipisciculture en fonction du riz irrigué*

En rizipisciculture, le riz doit rester l'objectif principal, le poisson n'étant qu'un complément utile. Il est donc nécessaire de définir les modifications indispensables pour adapter l'élevage des poissons aux conditions des rizières et aux exigences culturales du riz. Il est donc indispensable d'envisager quels sont, du fait de la culture et des exigences du riz, les impératifs auxquels seront soumises les techniques d'élevage du poisson. Il faudra également voir quels sont les aménagements piscicoles qui s'imposent si l'on désire obtenir la production la plus élevée possible.

2.3.1 *Conditions et méthodes de culture du riz.* En étudiant le cycle de croissance du riz, ses exigences et les opérations culturales en rizières, on constate que selon les techniques (semis direct ou semis en pépinière, suivi du repiquage des plants de riz), le cycle cultural du riz irrigué varie de 120 à 140 jours. Comme il est recommendé d'empoissonner les rizières environ 8 jours après le repiquage ou 1 mois après le semis direct, et qu'à la moisson on pratique généralement un assec de la rizière, il faut compter que la durée de l'élevage des poissons sera d'environ 100 jours par cycle cultural du riz. Selon les régions et les pays, il y a une ou plusieurs récoltes de riz par an. Il est donc possible de faire également plusieurs élevages successifs de poissons.

Généralement, il n'y a qu'une culture par an et, après la moisson, on laisse la rizière au repos. Dans certains pays cependant, l'on fait 2 cultures successives de riz par an (Indonésie, Madagascar et Chine, Province de Taiwan). Durant ce 'repos', la rizière est soit complètement à sec (elle peut alors servir de pâturage), soit inondée. Dans ce dernier cas, l'on peut continuer l'élevage des poissons ou y élever des canards, comme cela se fait à Madagascar. L'assec complet résulte généralement du fait qu'il n'y a pas maîtrise totale de l'eau ou parce que l'eau d'irrigation manque.

La mise à sec annuelle de la rizière a pour but, d'une part d'aérer le sol de la rizière et de provoquer la minéralisation de la vase et, d'autre part, de permettre, avant le repiquage de la saison suivante, les différents travaux culturaux (réfection des diguettes, application des engrais et labour). Etant donné qu'un assec d'un mois est largement suffisant, on peut donc envisager l'utilisation de la rizière, restée sous eau, durant la période qui va de la récolte du riz jusqu'à la mise à sec annuelle. Cet élevage complémentaire de poissons permet l'utilisation rationnelle de la rizière, après la récolte du paddy.

Si dans la même rizière on pratique deux cultures de riz successives, il est possible alors de faire, soit un élevage durant la première culture (sur environ 100 jours), suivi d'un second élevage, soit de faire un élevage continu durant les deux cultures de riz, en utilisant les mêmes poissons. Dans ce cas, il faut disposer d'un étang de stockage pour y entreposer les poissons à partir de la moisson de la première culture jusqu'à la remise en charge, après le semis ou le repiquage de la deuxième culture de riz.

Quand on pratique le semis direct, il faut attendre environ un mois avant de déverser des poissons en rizière. En cas de repiquage, une semaine environ suffit les plants étant alors enracinés. Si l'on empoissonne immédiatement après le repiquage, les poissons (surtout la carpe), en fouillant le sol à la recherche d'animaux du fond, risquent de faire basculer les plants. Les premiers jours après le repiquage, la lame d'eau dans la rizière ne dépasse généralement pas 5 cm.

En rizipisciculture et en tenant compte de la variété de riz utilisée, on obtient les meilleurs rendements en maintenant, durant la culture, une lame d'eau presque stagnante de 10 à 20 cm. Pour certaines espèces de poissons, cela peut présenter des inconvénients. L'eau dans les rizières est maintenue à un certain niveau au moyen de diguettes, dont la hauteur ne dépasse généralement pas 40 cm. En cas de hausse du niveau de l'eau, le poisson peut s'échapper.

Pour effectuer certaines opérations culturales, il peut être nécessaire de pratiquer un assec de la rizière notamment lors des applications des produits phytosanitaires ou d'épandage d'engrais. Il est évident qu'en rizières sans aménagements piscicoles, des assecs périodiques ne permettent pas la rizipisciculture. L'utilisation de produits phytosanitaires, parfois toxiques pour les poissons, s'oppose également à l'élevage en rizières, à moins d'avoir aménagé dans la rizière des refuges pour les poissons. Le sarclage mécanique, surtout si il est effectué dans une mince couche d'eau, peut présenter un certain danger pour les poissons car cela rend les eaux fort boueuses.

2.3.2 *Aménagements piscicoles des rizières.* Connaissant les techniques et pratiques culturales du riz irrigué ainsi que les avantages et inconvénients que présentent certaines de ces pratiques pour le poisson vivant en rizière, il importe de voir quelles sont les adaptations possibles des techniques piscicoles pour qu'elles puissent effectivement être mises en oeuvre en rizière. Ces adaptations portent essentiellement sur les problèmes de l'eau en rapport avec le poisson à élever en rizière.

2.3.2.1 Maîtrise de l'eau. En rizipisciculture intensive, la maîtrise de l'eau est indispensable, sinon il y a risque de submersion des diguettes avec fuite du poisson, ou danger d'assèchement prématuré des rizières et asphyxie des

poissons. La maîtrise de l'eau présente moins d'importance dans les régions où se pratique la rizipisciculture extensive (Inde, Malaisie, Mali, Libéria) et où l'on cultive parfois des variétés de riz flottant.

L'eau d'irrigation des rizières peut être de l'eau de pluie, du moins dans les régions où il y a des pluies régulières. En général, cependant, les rizières sont alimentées par irrigation. Dans certains pays (Inde, Indonésie), on utilise des eaux saumâtres. Les quantités d'eau nécessaires à l'irrigation des rizières dépendent de facteurs tels que le climat, la pluviométrie, les caractéristiques des sols et des digues. Coche (1967) signale qu'en Indonésie l'on utilise en moyenne 1–2 litres d'eau/sec/ha.

Avant d'envisager de faire de la rizipisciculture il faut être certain qu'il y aura un débit d'eau suffisant pendant la durée de l'élevage. En cas de fortes pluies, des inondations sont à craindre avec perte de poissons. On tente généralement de remédier à ces inondations en creusant des fossés de protection. Bien souvent il suffit de renforcer et de surélever les diguettes.

Le dispositif d'alimentation en eau le plus simple à mettre en oeuvre est la buse de bambou enterrée dans la diguette, éventuellement munie d'un grillage pour empêcher l'entrée de poissons étrangers et la fuite de ceux déversés dans la rizière. On peut également utiliser le système dit 'de digue percée' (goulotte munie de rainures et de grilles). Ce dispositif convient aussi bien pour l'entrée d'eau qu'en tant que trop-plein et système de vidange de la rizière lors de la mise à sec (récolte du riz et du poisson). Quelques petites planchettes permettent de régler le niveau d'eau. Des grilles ou claies en bambou tressé empêchent le poisson de quitter la rizière.

2.3.2.2 Drains périphériques et trous-refuges. Drains et trous-refuges sont indispensables pour obtenir des résultats d'élevage intéressants. A Madagascar les essais ont démontré l'augmentation du taux de survie des alevins dans les rizières munies d'un drain périphérique et d'un trou-refuge par rapport à celles qui n'en avaient pas. Les drains et trous-refuges permettent aux poissons de s'abriter et de s'y réfugier lors des mises à sec et des vidanges. Ils facilitent grandement leur capture.

En rizipisciculture extensive, on prévoit généralement des fossés, trous ou viviers qui s'aménagent dans les parties les plus basses des rizières. Les poissons peuvent s'y rassembler lors des baisses d'eau. Ce sont en même temps des endroits de stockage pour géniteurs et les alevins de repeuplement.

Les dimensions des drains et du trou-refuge varient d'une contrée à l'autre, en rapport avec les dimensions des rizières. Selon Coche (1967), la largeur des drains varie entre 50 et 180 cm et la profondeur de 30 à 90 cm. Ces drains se trouvent soit d'un seul côté, soit tout autour, soit en travers de la rizière. Parfois, plusieurs drains se rejoignent dans un trou.

On entend par drain périphérique un fossé large de 20 à 30 cm et profond de 30 à 40 cm, situé sur tout le pourtour de la rizière, au pied des diguettes. Le trou-refuge situé dans la partie la plus basse de la rizière est en communication avec le drain périphérique. Il mesure généralement de 0,50 à 0,80 m de diamètre et 0,80 m de profondeur. Pour de grandes rizières, il faut prévoir soit plusieurs trous-refuges soit des trous plus importants.

2.4 *Types de rizipisciculture*

Les productions aquicoles en rizières ne résultent pas de la mise en oeuvre d'une seule et unique technique d'exploitation. Au contraire, ces techniques diffèrent considérablement d'une région à l'autre. Selon Schuster, Kesteven et Collins (1954), les principaux facteurs qui jouent sont: les conditions locales, climatiques et autres; les espèces de poissons disponibles; les variétés de riz cultivées; les méthodes de culture du riz, y compris la fertilisation; les méthodes d'élevage des poissons, avec ou sans alimentation supplémentaire.

Par rapport à la culture et à la récolte du riz, l'aquaculture en rizières peut donner: (*i*) une seule production simultanée de riz et de poisson par an (*ii*) plusieurs productions simultanées successives de riz et de poisson, avec ou sans assec de la rizière après chaque récolte du riz (*iii*) un élevage de poisson en rotation après la récolte du paddy. Il est possible d'obtenir ainsi, en un an, deux récoltes de riz et une récolte de poisson.

Selon les espèces de poissons disponibles, leur taille à la mise en charge et les possibilités d'irrigation, on peut utiliser les rizières pour y élever des poissons de l'éclosion jusqu'à la taille d'alevins, des alevins pour en faire des poissons de consommation et même employer la rizière comme un étang de ponte (par exemple, pour la reproduction de la carpe commune (*Cyprinus carpio*) et de *Clarias lazera*).

Il y a ainsi différentes types d'exploitation piscicole en rizières. Coche (1967) a proposé de regrouper les types d'exploitation en deux catégories:

2.4.1 *La rizipisciculture extensive.* Dans les méthodes de capture, il n'y a pas de mise en charge rationnelle de la rizière. Le peuplement piscicole est constitué de poissons d'espèces sauvages qui se sont introduits dans les casiers rizicoles lors de leur inondation et qui existent naturellement dans les eaux permanentes d'irrigation. La rizipisciculture extensive se pratique surtout en Asie, dans des rizières de superficie relativement vastes, situées dans de grandes plaines alluviales. Elle existe aussi à Madagascar et au Mali, mais à petite échelle.

Dans les rizières exploitées de cette manière, il y a généralement plusieurs fossés ou viviers de 49 à 50 m^2 et d'environ 2 m de profondeur. Les poissons s'y concentrent lors des mises à sec des rizières. Les rendements en poisson varient entre 10 et 200 kg/ha/an, suivant la durée de l'élevage, les espèces, la nature et la fertilité des sols (Coche, 1967).

2.4.2 *La rizipisciculture intensive.* La rizipisiculture intensive est une culture de riz irrigué combinée à un élevage de poisson. Elle se pratique généralement en rizières de superficie moyenne, aménagées et empoissonnées rationnellement.

En rizipisciculture, du fait des poissons, le rendement en paddy augmente dans des proportions atteignant parfois jusqu'à 15% (Hora et Pillay, 1962). Cependant l'aménagement de drains et de trous-refuges diminue de 5 à 7% la superficie plantée en riz. Même dans ces conditions, le revenu du poisson compense largement la perte de paddy provenant d'une réduction des surfaces plantées. En rizipisciculture intensive, les rendements en poisson dépendent largement des espèces utilisées, de la durée de l'élevage, de la fertilité des rizières et d'apports éventuels de nourriture

supplémentaire. Les productions moyennes se situent entre 10 et 400 kg/ha/an.

3 Technique de la rizipisciculture

L'élevage du poisson en rizière peut débuter environ 8 jours après le repiquage du riz ou un mois après le semis direct. Au préalable, les diguettes de la rizière sont réhaussées et consolidées, le drain périphérique et le trou-refuge sont aménagés et les dispositifs d'entrée, de sortie et du trop-plein d'eau sont mis en place. Les travaux culturaux (labour, hersage, planage, épandage des engrais, repiquage) sont effectués. Entre 3 et 5 cm d'eau sont admis sur la plate-forme repiquée. Le drain périphérique et le trou-refuge étant ainsi remplis d'eau. Le riz est enraciné convenablement. L'on procède alors à l'empoissonnement de la rizière. En cours d'élevage, il y aura encore certains travaux à faire: sarclages, éventuelles applications d'engrais et de produits phytosanitaires.

3.1 *Choix des espèces pour l'élevage en rizières*

Coche (1967) a résumé les conditions auxquelles devraient répondre les espèces dont on envisage l'élevage en rizières. Ces espèces doivent: (*i*) supporter d'évoluer dans des eaux peu profondes; (*ii*) être adaptées à des températures d'eau élevées et à des teneurs basses en oxygène dissous; (*iii*) avoir une croissance rapide afin d'atteindre, très vite, la taille marchande; (*iv*) résister à une forte turbidité de l'eau; (*v*) ne pas manifester de tendance trop forte à s'échapper du milieu d'élevage.

Si le choix se porte sur des espèces non cultivées en étangs, il faut que l'on puisse, au moment voulu, capturer facilement les alevins nécessaires, dans les eaux naturelles. Dans certains pays l'on élève aussi des crustacés (crevettes en Inde; écrevisses à Madagascar) et l'on capture également des grenouilles (Madagascar).

De nombreuses espèces de poissons ont été utilisées en rizipisciculture (Tableau I). Les espèces les plus utilisées dans le monde sont: *Cyprinus carpio, Tilapia mossambica, Trichogaster pectoralis, Ophiocephalus striatus* et *Clarias batrachus*. Il y a également des espèces qui semblent avoir toutes les qualités requises pour l'élevage en rizières, notamment des malacophages. Ces espèces devraient être testées systématiquement en rizières afin de préciser quel pourrait y être leur rôle.

3.2 *Mise en charge et densité d'empoissonnement des rizières*

Nous n'envisageons ici que la rizipisciculture intensive, la seule où il y a une mise en charge contrôlée. Les densités à la mise en charge varient fortement d'une région à l'autre, en fonction des espèces, de la richesse de l'eau des rizières et du but poursuivi (grossissement d'alevins, production de poissons de consommation, *etc*). Le Tableau II groupe les données bibliographiques concernant les densités d'empoissonnement des rizières pour les diverses espèces et différents pays.

3.3 *Alimentation supplémentaire des poissons en rizières*

Des essais ont prouvé qu'en rizière (comme en étangs d'ailleurs), on double pratiquement les rendements en distribuant régulièrement une nourriture artificielle aux alevins. Pour que cette opération soit rentable, il est nécessaire de disposer, sur place, de déchets ou de sous-produits de

TABLEAU I

ESPÈCES DE POISSONS UTILISÉS EN RIZIPISCICULTURE DANS LE MONDE (CITÉES PAR ORDRE ALPHABÉTIQUE)

Espèce	*Asie*	*Afrique*	*Europe*	*Amérique du Nord*	*Amérique du Sud*
Anabas testudineus	×				
Carassius auratus	×	×	×		
Catla catla	×				
Chanos chanos	×				
Cirrhina mrigala	×				
Clarias batrachus	×				
C. lazera		×			
Cyprinus carpio	×	×	×	×	
Eleotris legendrei		×			
Haplochromis mellandi		×			
Helostoma temmincki	×				
Heterotis niloticus		×			
Ictalurus punctatus				×	
Ictiobus cyprinellus				×	
Labeo rohita	×				
Lates calcarifer	×				
Lepomis macrochirus				×	
Micropterus salmoides				×	
Mugil corsula	×				
M. parsia	×				
M. tade	×				
Mystus gulio	×				
Odontesthes bonariensis					×
Ophiocephalus striatus	×				
Osteocheilus hasseltii	×				
Paratilapia polleni		×			
Puntius javanicus	×				
Tilapia macrochir		×			
T. mossambica	×	×			
T. nilotica		×			
T. rendalli		×			
T. zillii		×			
Tinca tinca			×		
Trichogaster pectoralis	×				
T. trichopterus	×				

TABLEAU II
DENSITES D'EMPOISSONNEMENT DES RIZIÈRES EN MONOCULTURE

Pays	*Espèce*	*Densité (nombre d'alevins/are)*	*Taille des alevins (cm)*	*Références*
Chine (Province de Taiwan)	*Tilapia mossambica*	70–80	—	Hickling (1962), Coche (1967)
Côte-d'Ivoire	*Heterotis niloticus*	20–60	—	Vincke (1976)
	Tilapia macrochir	20–80	—	Vincke (1976)
	T. nilotica	30–80	—	Vincke (1976)
Indonésie	*T. mossambica*	10–100	1–3	Coche (1967)
	Cyprinus carpio var. *flavipinnis*	600–1 000	1	Hickling (1962), Coche (1967)
	C. carpio var. *flavipinnis*	40	2–3	Coche (1967)
	C. carpio var. *flavipinnis*	10–20	8–12	Coche (1967)
Japon	*Cyprinus carpio*	2[a]	5–7,5	Hora et Pillay (1962)
	C. carpio	125[b]	5–7,5	Hora et Pillay (1962)
	C. carpio	12–16[a]	—	Hora et Pillay (1962)
	C. carpio	40[a]	—	Hora et Pillay (1962)
	C. carpio	30–200	—	Hickling (1962)
Libéria	*Tilapia macrochir*	50	—	Vincke (1976)
Madagascar	*Cyprinus carpio*	10	5–6	Coche (1967)
	C. carpio	25	4–5	Vincke (1976)
	Tilapia macrochir	25	4–5	Vincke (1976)
	T. mossambica	25–50	8–10	Vincke (1976)
	T. nilotica	25	4–5	Vincke (1976)
	T. rendalli	25–50	3–5	Vincke (1976)
	T. zillii	25–50	3–8	Vincke (1976)
Rhodésie	*T. mossambica*	220–320	—	Coche (1967)
Viet Nam	*Cyprinus carpio*	200	—	Coche (1967)
	C. carpio	12	—	Hora et Pillay (1962)

[a] Sans alimentation supplémentaire des poissons
[b] Avec alimentation supplémentaire des poissons

culture d'un prix abordable et d'une certaine valeur alimentaire. Le paysan dispose souvent de son de riz, de manioc frais ou de cossettes, de maïs, *etc* dont peuvent bénéficier les poissons.

L'alimentation artificielle des poissons en rizières est surtout pratiquée au Japon et parfois à Madagascar (Huet, 1970). On utilise des produits divers: feuilles de manioc, son de riz, tourteaux de coton ou d'arachide, cocons de vers à soie, balayures de cases, *etc.* On peut également préparer une provende et la distribuer régulièrement aux poissons.

Les doses d'aliments à distribuer diffèrent largement d'un pays à l'autre, selon les espèces élevées, la densité, le type d'aliments, *etc.* A Madagascar on donne généralement une ration journalière équivalente à 1/10 du poids de poisson présent. Ailleurs l'on distribue des rations allant de 2 à 8% de ce poids.

3.4 *Polyculture en rizières*

La rizière constituant un ensemble de niches écologiques, diverses espèces à régimes alimentaires différents mais complémentaires, permettent d'exploiter plus efficacement la rizière.

En Inde, on associe *Catla catla, Cirrhina mrigala* et *Labeo rohita* à d'autres espèces telles que *Anabas testudineus, Trichogaster* et *Mugil.* En Indonésie, l'on combine la carpe commune avec *Osteochilus hasseltii, Puntius javanicus* et parfois *Chanos chanos.* En Malaisie, l'on élève en association le sepat siam (*Trichogaster pectoralis*) avec *Clarias batrachus* et *Ophiocephalus.* A Madagascar la carpe commune est associée à différents *Tilapia* (Vincke, 1975). Au Zaïre, Coche (1967) a élevé en association *Tilapia macrochir, T. rendalli* et *Haplochromis mellandi.*

Des recherches de polyculture en rizières devraient être poursuivies afin de préciser quelles sont les associations les plus intéressantes, les espèces d'accompagnement ne faisant pas concurrence à l'espèce principale en exploitant des niches écologiques différentes.

3.5 *Conduite de l'élevage en rizières*

3.5.1 *L'eau dans les rizières.* Au fur et à mesure de la croissance du riz, le paysan augmente la hauteur d'eau dans la rizière, sans cependant dépasser 15–20 cm. Pour permettre aux poissons de circuler assez librement, entre les plants de riz, il est nécessaire d'avoir un minimum d'eau sur la plate-forme repiquée. Si pour certains travaux, notamment les traitements phytosanitaires contre les borers ou la piriculariose, il faut baisser le niveau d'eau ou mettre temporairement la rizière à sec, il est recommendé de le faire lentement afin de donner aux poissons l'occasion de se réfugier dans les drains et le trou-refuge.

3.5.2 *Sarclages.* Les sarclages peuvent se faire normalement, sans aucun danger pour les poissons. En plus de son utilité pour le riz, le sarclage, en remuant le fond, déloge des vers et des larves d'insectes que le poisson, surtout la carpe, s'empresse d'ingurgiter. Après sarclage, les algues se développent assez souvent avec vigueur. Ces algues faisant partie de la nourriture de certains poissons (par exemple *Tilapia mossambica, Catla catla, Chanos chanos* et *Puntius javanicus*), il est donc avantageux d'utiliser ces espèces en rizières pour réduire le développement des algues.

Certains poissons herbivores tels que *Tilapia rendalli* et *T. zillii* consomment la jeune végétation adventice réduisant ainsi le nombre de sarclages nécessaire. Au Libéria et dans certains pays d'Asie, l'on utilise des herbicides tels que MCPA (4 chloro-2 methylphenoxyacetic acid) et U 46. Il y a peu de renseignements au sujet de la toxicité de ces produits envers les poissons et il nous paraît indispensable d'effectuer des recherches dans ce domaine.

3.5.3 *Application d'engrais en cours de culture.* Les techniques modernes de riziculture nécessitent l'épandage d'un engrais azoté, vers le 45ème jour après le repiquage. A Madagascar on utilise généralement du sulfate d'ammoniaque (300–400 kg/ha) et l'épandage se fait lors

d'un assec de quelques heures. Cette opération culturale ne présente aucun danger pour les poissons des rizières dans lesquelles existent drains et trou-refuge. De même lors de l'épandage de sulfate d'ammoniaque à la surface de l'eau, sans assec, il n'y a que de très rares mortalités (Vincke, 1976).

Au Libéria, quand cela s'avère nécessaire, l'on applique vers le 80ème jour après le repiquage, une dose de 50 kg/ha d'urée à 45% de N. Durant cette opération, la rizière reste à sec une demie journée (Vincke, 1976).

3.5.4 *Utilisation de produits phytosanitaires.* Depuis une dizaine d'années l'utilisation d'une multitude de produits chimiques a été préconisée pour lutter contre les insectes et les maladies des plants de riz. L'emploi massif de ces produits phytosanitaires a permis d'atteindre des rendements de plus en plus élevés. Beaucoup de ces produits sont très toxiques, non seulement pour les poissons mais également pour d'autres animaux et leurs effets néfastes sont maintenant assez bien connus. C'est en grande partie à cause de l'emploi massif de tels produits que la rizipisciculture a connu depuis quelques années un déclin au Japon, en Chine (Province de Taiwan) et en Italie.

Les essais menés au Japon par Matida, Kimura et Tamakawa (1958) ont démontré la toxicité du Dieldrin et de l'Endrin vis-à-vis de la carpe commune élevée en rizières, alors que des insecticides tels que Diazinon, Dipterex, DDVP et Folidol, aux doses habituelles, n'avaient pas d'effets néfastes apparents. Les essais sur l'action du Lindane à l'Institut International pour la Recherche sur le Riz ont démontré que la carpe commune est moins sensible que les différentes espèces de *Tilapia* (IRRI, 1964).

Les essais effectués à Madagascar depuis 1967–68 sur la toxicité du Lindane sur les poissons en rizières, permettent d'affirmer que le Lindane (granulés à 6%) à une dose de 0,5 kg/are ne cause pratiquement aucun dégât aux poissons, à condition de n'épandre le produit que sur la plate-forme repiquée, lors d'une mise à sec. Lors d'un épandage en pleine eau on constate chez la carpe une mortalité atteignant parfois 7–8% (Vincke, 1976).

3.5.5 *Récolte du riz et du poisson.* Si le riz mûrit généralement bien en rizière sous eau, on pratique parfois un assec durant une semaine avant la moisson afin de rendre la maturation plus homogène. Il est préférable de ne pas faire cette opération dans des rizières empoissonnées. Sinon il importe de surveiller le comportement des poissons afin de les transférer dans un petit étang de stockage, si cela s'avérait indispensable. On pourrait évidemment, à ce moment, procéder à la pêche des poissons et considérer l'élevage comme terminé. En général, on draine la rizière un ou deux jours avant la moisson. La mise à sec doit être lente pour permettre aux poissons de se grouper dans les drains et le trou-refuge. Si le poisson récolté est destiné à la vente ou à la consommation immédiates, il n'y a pas de précautions spéciales à prendre après la récolte. Par contre, si l'on décide d'en continuer l'élevage (élevage complémentaire en rizière ou poursuite de l'élevage en étang), il est indispensable d'avoir à proximité un étang de stockage d'une superficie adequate pour y déverser les poissons provenant de la rizière.

3.5.6 *Elevage complémentaire.* Dans bien des cas il est possible, après la récolte du riz, de remettre la rizière sous eau pour y poursuivre l'élevage de poissons. Cet élevage complémentaire se fait donc avec les mêmes poissons, tout en ajustant cette seconde mise en charge aux environs de 2–3 kg/are. Il est bon, avant la seconde mise en charge, de remettre du fumier en tas dans la rizière, à raison de 15–20 kg/are. L'on favorise ainsi la croissance de plancton qui s'ajoute aux détritus végétaux laissés dans la rizière après la récolte. Il est souhaitable de maintenir l'eau à un niveau assez élevé (30–40 cm) et de garder en bon état les diguettes, les drains et les trous-refuges.

La durée de cet élevage complémentaire est variable. Elle dépend du but poursuivi et des quantités d'eau disponibles pour l'irrigation. Les rendements que l'on peut espérer durant l'élevage complémentaire sont variables et dépendent de nombreux facteurs (saison et température de l'eau, profondeur de la rizière, quantité de nourriture naturelle disponible, application ou non d'une alimentation artificielle, durée de l'élevage, *etc*). Le pourcentage d'accroissement en poids durant l'élevage complémentaire va de 25 à 100%, selon les conditions. Signalons qu'en nourrissant les carpes pendant un élevage complémentaire de deux mois environ, on peut faire doubler leur poids (Vincke, 1976).

3.6 *Productions piscicoles en rizières*

La production piscicole en rizières varie fortement d'un pays à l'autre, en fonction du mode d'exploitation (rizipisciculture intensive ou extensive), de l'espèce élevée, de la profondeur de la rizière, de la fertilité du sol et de l'eau, des soins et de l'intérêt apportés par le fermier à la culture du riz et à la production de poisson (Huet, 1970).

En rizipisciculture extensive, les rendements varient entre 1,5 et 3,0 kg/ha/an en Indonésie et 40 kg/ha/an en Malaisie (Huet, 1970). Coche (1967), citant divers auteurs, mentionne des productions allant de 135 kg/ha en 6–10 mois (Malaisie) à 100–200 kg/ha/an (Inde).

En rizipisciculture intensive, les productions sont nettement plus élevées et varient entre 100 et 200 kg/ha/an avec une moyenne de 120–150 kg/ha/an. Comme le signale Huet (1970) cette valeur moyenne est d'ailleurs très relative. Si on la calcule par mois, la production est souvent voisine de 100 kg/ha/mois, mais les périodes de production étant, au cours d'une année, limitées à quelques semaines, la production annuelle est alors sérieusement réduite. En alimentant les poissons élevés en rizières, la production augmente fortement. Au Japon, en nourrissant des carpes communes élevées en rizières, on a obtenue des rendements atteignant 1 100–1 800 kg/ha/an (Coche, 1967).

Le Tableau III regroupe les données concernant les productions obtenues en rizipisciculture dans le monde. Ce tableau est basé sur les renseignments publiés par Coche (1967), complété par quelques résultats de recherches publiés ces dernières années.

3.7 *Dégâts causés au riz irrigué par les poissons*

Dans certains pays, les riziculteurs se méfient de la rizipisciculture, car ils craignent que les poissons 'mangent le riz'. Néanmoins, très souvent, à la moisson du riz, ces paysans capturent avec empressement les poissons 'sauvages' qui se sont introduits dans leurs rizières. Ils ne calculent pas la valeur de ces poissons qui, dans bien des cas, dépasse 25% de la valeur du paddy récolté dans la rizière. Cela compense largement les dégâts causés éventuellement au riz par ces poissons.

TABLEAU III
PRODUCTIONS PISCICOLES EN RIZIÈRES

Continent et pays	*Méthodes de rizipisciculture*	*Production de poisson (kg/ha)*	*Références*
I *Asie ou région Indo-Pacifique*			
Inde	Rizipisciculture extensive	100–200 kg/an	Pillay et Bose (1958)
	Rizip. intensive expérimentale	17,5–152,5 kg/71 jours	Muddanna, Halappa et Rajagopal (1970)
	Rizip. intensive expérimentale (*Tilapia mossambica* + crevettes)	*Tilapia* 100 kg/3 mois ; crevettes 200 kg/3 mois	Raman (1968)
Chine (Province de Taiwan)	Rizip. intensive (*T. mossambica*)	220 kg/an	Hickling (1962)
Indonésie	Rizip. extensive (carpe commune)	150 kg/4–6 mois	Hofstede et Ardiwinata (1950); Huet (1956)
	idem (*T. mossambica*)	75–100 kg/3–4 mois	*ibid.*
	Rizip. intensive	30–50 kg/40–60 jours	Hora et Pillay (1962)
	Rizip. extensive	3 kg/6 mois	Hora et Pillay (1962)
Japon	Rizip. intensive (carpe commune, production d'alevins)	100–200 kg/an	Hickling (1962)
	idem, avec alimentation artificielle	700–1 000 kg/an	Koronuma (1954)
	idem, avec alimentation artificielle, récolte de carpes de 2 ans	750–1 100 kg/an	Koronuma (1954)
	idem, mais récolte de carpes de 3 ans	1 100–1 800 kg/an	*ibid.*
	idem	jusqu'à 2 250 kg/an	Hora et Pillay (1962)
Malaisie	Rizip. extensive (*Trichogaster pectoralis*)	135 kg/6–10 mois	Schuster (1955) ; Hora et Pillay (1962)
	Rizip. intensive	10–400 kg/6–10 mois	Coche (1967)
	Rizip. intensive (*T. pectoralis* + divers)	132 kg/ha	Tan *et al* (1973)
Thaïlande	Rizip. intensive (*Tilapia nilotica* et carpe)	210 kg/ha	Swingle et Shell (1972)
	idem + nourriture	250 kg/ha	*ibid.*
	idem + nourriture + fertilisation	418 kg/ha	*ibid.*
Viet Nam	Rizip. intensive (carpe commune)	80–100 kg/3 mois	Coche (1967)
	idem	100–150 kg/6–7 mois	*ibid.*
	Rizip. extensive	10–20 kg/2 mois	Hora et Pillay (1962)
II *Afrique*			
Côte d'Ivoire	Rizip. intensive monoculture *Heterotis niloticus*	139 kg/ha/an–120 jours	Vincke (1976)
	idem monoculture *T. nilotica*	44,5 kg/ha/an–120 jours	*ibid.*
	idem monoculture *T. macrochir*	37,7 kg/ha/an–120 jours	*ibid.*
Gabon	Rizip. intensive polyculture (*T. nilotica* + *H. niloticus*)	680 kg/an–6 mois	*ibid.*
Libéria	Rizip. intensive (*T. macrochir*)	234–283 kg/ha/an	*ibid.*
Madagascar	Rizip. intensive (carpe commune)	200–250 kg/an	Lemasson (1954)
	idem (carpe + *Carassius*)	200 kg/an	Kiener (1956)
	idem (carpe commune)	150–200 kg/130 jours	Rabelahatra (1972)
Rhodésie	*idem* (*T. mossambica*)	max. 70 kg/4 mois	Maar (1959)
Tanzanie	*idem* (*T. nilotica*)	110 kg/an	Schuster (1955)
Zaïre	*idem* polyculture *Tilapia* + *Haplochromis mellandi*	100 kg/an	Coche (1960)
III *Amériques*			
E.U.A.	Rizip. intensive (*Ictalurus* + *Ictiobus*)	119 kg/an	Green et Mullins (1959)
Brésil	Rizip. intensive (carpe + *T. rendalli*)	166–562 kg/an	Coche (1967)
IV *Europe*			
Italie	Rizip. intensive (carpe + *Tinca* + *Carassius*)	100 kg/an	Coche (1967)

Il ne semble pas y avoir de dégâts dans les rizières bien aménagées et cultivées correctement avec la maîtrise complète de l'eau. Les seuls dégâts imputables aux poissons (Madagascar et Mali), concernent des champs de riz, sans maîtrise de l'eau et soumis à des inondations périodiques (Matthes, 1976; Kierner, 1956, 1962, 1963; Rabelahatra, 1972; Vincke, 1972, 1972b). Dans ces conditions, les dégâts peuvent être assez importants, surtout si les eaux recouvrent des jeunes plants et qu'il y a, parmi les poissons circulant en rizières inondées, des espèces phytophages. Matthes (1976), pour les rizières des environs de Mopti (Mali), estime que par rapport aux superficies, les dégâts causés par les poissons ne dépassent pas 10–15%.

Quand, à certaines phases de sa croissance, le riz irrigué est complètement submergé pendant plusieurs jours, la récolte peut être complètement anéantie, non pas à cause des poissons, mais parce que le riz ne résiste pas à un tel traitement. C'est le cas notamment lorsque l'immersion survient au moment de la floraison du riz. Il n'est donc pas toujours certain qu'en période d'inondation, tous les dégâts causés au riz soient imputables aux poissons (Vincke, 1976).

Avec la maîtrise complète de l'eau et une mise en charge contrôlée, il ne peut y avoir de dégâts au riz du fait des poissons, car les espèces déversées en rizières ne présentent aucun danger pour le riz. Il a d'ailleurs été prouvé que des espèces phytophages, telles que *Tilapia rendalli* (Coche, 1960) et *T. zillii*, ne s'attaquent pas aux plants de riz si la mise en charge est effectuée correctement et à temps voulu. Avec ces espèces, les rendements en paddy sont aussi élevés que dans les rizières empoissonnées avec de la carpe commune (Vincke, 1972).

3.8 *Lutte contre les végétaux, mollusques et moustiques en rizières irriguées*

En rizipisciculture, les paysans sont confrontés avec trois principaux problèmes sanitaires: (*i*) les plantes adventices et les algues; (*ii*) la lutte contre les mollusques, vecteurs de la bilharziose; (*iii*) la lutte contre les oeufs et larves des moustiques, vecteurs de nombreuses maladies.

Les mauvaises herbes et les algues sont des concurrentes sérieuses pour le riz. Elles peuvent provoquer des pertes de rendement pouvant atteindre jusqu'à 50% (Chateau, 1957). Il a été démontré qu'en utilisant rationnellement certaines espèces de poissons, il est possible de lutter efficacement contre les plantes adventices. Les poissons qui conviennent le mieux sont les espèces herbivores telles que *Puntius javanicus, Tilapia rendalli* et *T. zillii* et les mangeurs d'algues tels que *Tilapia mossambica* et *Trichogaster pectoralis* (Coche, 1967).

La prolifération des mollusques en rizières irriguées pose un grave problème sanitaire dans les régions tropicales. La lutte chimique contre les mollusques ne donne pas entière satisfaction et les produits utilisés tuent généralement les poissons. Eliminer la végétation aquatique dont se nourrissent les mollusques est un moyen de diminuer leur nombre. Des poissons herbivores peuvent contribuer à l'élimination de ces végétaux. Certains poissons tels que *Tilapia zillii, T. nilotica* et *T. mossambica* détruisent les pontes de mollusques (Vincke, 1972a). Comme cela a déjà été signalé par ailleurs, un des moyens les plus efficaces pour lutter contre les mollusques en rizières irriguées est d'utiliser des poissons malacophages tels que *Haplochromis mellandi* (Coche, 1960) et *Astatoreochromis alluaudi*. Il y a certes encore d'autres espèces dont l'élevage en rizières pourrait être tenté.

Certains poissons consomment les larves de moustiques. Comme pour la lutte contre les mollusques, il importe d'éliminer les végétaux et là encore les poissons phytophages peuvent rendre service. Coche (1967) signale à ce propos les résultats intéressants obtenus en Indonésie et en Malaisie avec *Tilapia mossambica* et au Zaïre avec *Tilapia rendalli*. A Madagascar, l'on a introduit *Gambusia holbrooki* en 1949–50 dans le but de lutter contre les moustiques.

4 L'aquaculture en rizières dans le monde

I 'aquaculture en rizières se pratique plus ou moins intensivement dans cinq continents: Asie (région Indo-Pacifique), Afrique, Amériques (Nord et Sud) et Europe.

Nous examinerons sommairement les réalisations et la situation actuelle de la rizipisciculture dans les contrées et pays de chacun de ces continents.

4.1 *Asie ou Région Indo-Pacifique*

C'est dans ce continent que l'élevage en rizières est le plus pratiqué. A notre connaissance, la rizipisciculture y concerne 14 pays: Bangladesh, Birmanie, Chine (y compris Taiwan), Hong Kong, Inde, Indonésie, Japon, Kalimantan, Kampuchea, Malaisie, Philippines, Sri Lanka, Thaïlande et Viet Nam.

4.1.1 *Bangladesh.* Schuster (1952) affirmait que la rizipisciculture était practicable dans les 8 173 ha de riziculture en Bangladesh (à l'époque l'Est du Pakistan). Il signale que *Cyprinus carpio* et *Trichogaster pectoralis* sont généralement utilisés dans certaines de ces rizières. Le même auteur préconisait des essais avec *Tilapia mossambica*.

4.1.2 *Birmanie.* Selon Hora et Pillay (1962), la riziculture irriguée en Birmanie occupait 510 000 ha en 1962. Il y aurait eu des essais de rizipisciculture dans ce pays, mais nous n'avons pas trouvé de trace des résultats dans la littérature dont nous avons pu disposer.

4.1.3 *Chine.* D'après Coche (1967), la rizipisciculture est pratiqué en Chine, mais à petite échelle. Nous n'avons pu obtenir de précision sur la situation actuelle. Dans la Province de Taiwan, l'élevage en rizières de *Tilapia mossambica* a connu un développement spectaculaire après la seconde guerre mondiale, remplacant dans certaines régions la carpe commune, parce que *T. mossambica* a une meilleure croissance en climat subtropical, se reproduit plus facilement que la carpe, s'adapte mieux aux eaux peu profondes et devient marchand à une plus petite taille (50–100 g). Des précautions sont prises contre le froid, du moins dans la partie nord de l'île. Les alevins ne sont déversés en rizières qu'au moment où la température de l'eau dépasse 15°C. Le poisson séjourne en rizières environ 7 mois, pendant deux cultures de riz successives. Les techniques d'exploitation ont été décrites en détail par Coche (1967). Avec au départ une mise en charge de 7 000 à 8 000 petits alevins de *T. mossambica* ou de 120–180 kg de plus gros alevins à l'hectare, la production moyenne est de 220 kg de poisson par hectare en 7 mois avec fumure organique et alimentation consistant en un mélange de son de riz et de farine de soja.

En 1956, il y avait dans la Province de Taiwan, 7 328 ha de rizipisciculture. En 1961, il n'y en avait plus que 927 ha. Il restait 123 ha en 1966 et seulement 26 ha en 1972 (Hwang, 1972). Cette diminution constante résulte surtout du fait que de plus en plus, les riziculteurs utilisent de nouvelles variétés de riz à tiges courtes ne supportant que 5–6 cm d'eau. Il y aurait également en cause une hausse du coût de la main-d'oeuvre et l'utilisation intensive de produits phytosanitaires qui rendent actuellement la rizipisciculture aléatoire.

4.1.4 *Hong Kong.* Il n'y a rien de précis dans la littérature sur la situation de la rizipisciculture dans ce territoire, à l'exception d'un rapport de Indrasena (1957) cité par la FAO (1958). Selon Hora et Pillay (1962), il y avait à Hong Kong 200 ha de riz irriguée avec élevage de poisson.

Indrasena signale des pertes d'environ 50% parmi les carpes communes élevées en rizières à Hong Kong; pertes causées par des poissons prédateurs, des serpents, des oiseaux. Il estime que ces pertes seraient proportionnellement moindres dans des rizières plus grandes (surfaces supérieures à un ou deux acres) (0·4–0·8 ha).

4.1.5 *Inde.* On pratique une rizipisciculture extensive en eaux saumâtres dans les régions deltaïques du Bengale occidental et de la province de Madras. Comme le signale Coche (1967), les pratiques sont très similaires à celles en usage en Malaisie (voir 4.1.10). Les poissons capturés sont généralement des espèces d'estuaires et des crevettes. Pillay et Bose (1957) mentionnent *Mugil parsia, M. tade, M. corsula, Lates calcarifer* et *Mystus gulio* ainsi que les crevettes *Palaemon carcinus, P. semisulcatus, Penaeus carcinus, Metapenaeus monoceros* et *M. brevicornis*. Les captures se situent entre 100 et 200 kg/ha/an. Depuis quelques années, le Département des Pêches recommande l'utilisation en rizipisciculture des carpes indiennes *Catla catla, Cirrhina mrigala* et *Labeo rohita*.

Hora et Pillay (1962) estimaient qu'il y avait en Inde 1 619 ha de rizières irriguées où se pratiquait l'élevage de

poissons. En 1973, il y avait 227 000 ha de rizières irriguées où il existe des possibilités de faire de la rizipisciculture (Pillay, 1973).

Raman (1968) fait état des résultats encourageants d'essais d'élevages de crevettes en association avec *Tilapia mossambica* en rizières e'eaux saumâtres dans le Kérala. Les crevettes sont entrées librement dans les rizières tandis que des alevins de 36–80 mm de *T. mossambica* y ont été déversés à une densité approximative de 4 800 alevins/ha. L'essai a duré 3 mois alors que la période de capture des crevettes en rizières côtières dure généralement 6 mois (novembre–avril). En 3 mois, *T. mossambica* a atteint une taille moyenne de 16,2 cm. La production de poissons était de 100 kg/ha/an dans la rizière expérimentale contre 68 kg/ha/an dans les enclos témoins, sans crevettes, avec des taux de survie respectifs de 18,7% et de 13,75%. La production des crevettes était de 200 kg/ha et composée des espèces suivantes: *Metapenaeus dobsoni, M. monoceros* et *Penaeus indicus* (Raman, 1968). L'auteur signale les possibilités d'élever *T. mossambica* comme poisson d'accompagnement, avec les crevettes, en rizières. Il préconise la mise en charge avec des alevins de 5–6 cm et une durée d'élevage de 6 mois.

Muddana, Halappa et Rajagopal (1970) ont publié les résultats d'essais de rizipisciculture avec la carpe commune (*Cyprinus carpio*) conduits à Hebbal (Bangalore), en rizières fertilisées, sans alimentation artificielle. Ils ont utilisé des alevins de 28–80 mm et d'un poids de 0,95–1,30 g à trois densités différentes: 5 000, 7 500 et 10 000 alevins/ha. Le riz a été récolte 71 jours après le repiquage. Les carpes ont été récupérées immédiatement après. Les rendements en poisson ont varié entre 18 et 69,5 kg/ha selon les traitements (densité). Dans un cas (densité 5 000 alevins/ha) on a atteint 152,5 kg/ha avec une survie de 60%. Dans certaines rizières, il y a eu des pertes de carpillons après des inondations. Les auteurs signalent avoir utilisé un insecticide(Rogor) mais ne mentionnent pas s'ils ont constaté des mortalités après ce traitement.

4.1.6 *Indonésie.* Les premiers essais d'élevage de poisson en rizières à Java datent de 1860 (Ardiwinata, 1958). Selon le même auteur, en 1955, il y avait en Indonésie 90 492 ha de rizipisciculture produisant 9 160 tonnes de poisson de consommation. Pillay (1973) signale qu'il y a en Indonésie un potential de 3 millions d'hectares de rizières irriguées où l'on pourrait élever du poisson. Les techniques de rizipisciculture en vogue en Indonésie ont été décrites en détail par Ardiwinata (1958), Hickling (1962), Coche (1967) et Huet (1970).

Selon Ardiwinata (1958) il existe une rizipisciculture extensive dans environ 4 millions d'hectares de rizières produisant en moyenne environ 1,5 kg/ha. La rizipisciculture intensive est surtout importante dans la province occidentale de Java où se trouvent environ les trois quarts des rizières empoissonnées. L'espèce principale est la carpe (*Cyprinus carpio* var. *flavipinnis*) qui représente environ 85% de la production totale provenant des rizières. On élève également *Tilapia mossambica, Chanos chanos, Helostoma temmincki, Osteochilus hasseltii* et *Puntius javanicus*. A part *T. mossambica*, les autres espèces sont surtout élevées en rizières en vue de la production d'alevins pour la vente aux propriétaires d'étangs de pisciculture (Coche, 1967).

Nous ne pouvons pas ici entrer dans les détails des différents types d'élevages pratiqués en rizières en Indonésie. Coche (1967) les a résumé comme suit: (*i*) Riz et poisson en rotations successives: (*a*) annuellement une culture de chacun (méthode palawidja). Avec des alevins de 2–3 cm (densité 4 000 alevins/ha) il est possible de faire plusieurs récoltes après un élevage de 1 à 3 mois. Pour obtenir de plus grosses carpes, 1 000 à 2 000 carpillons/ha de 8–12 cm séjournent 2 à 3 mois en rizières. La durée totale d'élevage est de 4 à 6 mois. La production totale durant cette période se situe entre 75 et 150 kg/ha; (*b*) trois cultures de poissons en 2 ans et parfois 5 en un cycle de 3 ans (méthode penjelang): ceci n'est applicable que s'il y a des possibilités d'irriguer les rizières toute l'année. Dans chaque cycle de 2 ans, le riz est cultivé 3 fois durant 5 mois, soit 15 mois au total. Entre ces périodes, les rizières restent sous eau et il est possible d'y élever des carpes durant environ 2 mois. Trois récoltes de poissons peuvent ainsi être obtenues durant chaque cycle de 2 années.

(*ii*) Production simultanée de riz et de poisson: (*a*) du repiquage du riz jusqu'au second sarclage (7 à 9 semaines): 60 000 alevins de 1 cm/ha, qui mesurent 3–5 cm à la récolte; (*b*) du repiquage jusqu'à la floraison du riz (12–16 semaines): densité à la mise en charge: 1 000–2 000 alevins de 8–10 cm/ha. Récolte de poissons de consommation de 14–16 cm et de 50–70 g. La production totale varie entre 75 et 100 kg/ha; (*c*) du second sarclage jusqu'à la floraison (5–7 semaines).

Comme le signale Huet (1970), c'est un système très souple dont les caractéristiques essentielles sont: productions dans la limite de courtes périodes de 1 à 3 mois et spécialisation des fermiers qui produisent des catégories bien déterminées de poissons (alevins, fingerlings et poissons de consommation).

4.1.7 *Japon*[1]. Selon Tamura (1961) l'élevage de poissons en rizières date de 1844 mais il est admis, en fait, que la pratique de la rizipisciculture est plus ancienne. La carpe commune est le poisson de base. La rizipisciculture a été prospère au Japon, surtout pendant la seconde guerre mondiale, mais de 1944 à 1949 la production de poisson est tombée de 4 436 tonnes à 937 tonnes. En 1958 elle n'était plus que de 462 (Hickling, 1962). Maintenant la rizipisciculture au Japon est en nette régression et il n'y a plus que 0,3 à 0,5% des rizières irriguées qui sont encore empoissonnées (Coche, 1967). Les causes principales de la régression de la rizipisciculture au Japon sont liées à l'intensification de l'agriculture (Huet, 1970). Au Japon, comme à Taiwan, le paysan donne priorité aux rendements rizicoles les plus hauts possibles. Pour cela, il utilise de plus en plus d'engrais minéraux et d'insecticides puissants. De telles pratiques ne sont plus compatibles avec la rizipisciculture.

Hickling (1962) a décrit les méthodes de rizipisciculture japonaises en se basant notamment sur les travaux de Kyokai (1957) et de Koronuma (1954). Selon Huet (1970), les principales caractéristiques de la rizipisciculture au Japon sont: une culture intensive avec usage de fumure et de nourrissage des poissons permettant d'obtenir des productions de poissons d'assez forte taille: 100–250 g en deux années d'élevage, 350–750 g après trois années en rizières. Etant donné le climat tempéré du Japon, la carpe

[1] En ce moment, il n'y a pas de récolte de carpe commune dans les rizières au Japon, principalement à cause de l'emploi d'insecticides. Voir 'The Culture of Common Carp in Japan' par R. Suzuki dans ce volume.

commune ne se reproduit qu'une fois l'an, au printemps (avril-mai). De gros reproducteurs (généralement une femelle et trois mâles) sont placés en petits étangs de ponte (3 à 16 m^2), avec des herbes comme supports pour les oeufs. Souvent cet étang de ponte est aménagé dans une des rizières. Après la ponte, les herbes sont transférées dans une petite rizière pour éclosion et premier grossissement. Le repiquage a lieu en juin et les carpillons sont déversés en rizières fertilisées 10 jours après le repiquage. Le récolte se fait en septembre–octobre et les carpes sont transférées en étangs d'hivernage. Au printemps suivant, elles seront replacées en rizières pour atteindre la taille marchande.

Les densités à la mise en charge varient: alevins de 3 à 5 cm: 2 000 à 4 000/ha sans alimentation supplémentaire; 10 000 à 15 000/ha avec alimentation. Carpes d'un an (12–18 cm): 1 200 à 1 600/ha avec seulement nourriture naturelle; 4 000/ha avec alimentation supplémentaire. A de telles densités et avec nourrissage, l'on obtient entre 700 et 1 800 kg de poisson par hectare (Hickling, 1962; Coche, 1967).

4.1.8 *Kalimantan* (*Borneo*). Selon Hora et Pillay (1962), il y avait à l'époque 17 500 ha de rizières irriguées. Il est vraisembable qu'il y a dans ces rizières une production piscicole mais, à notre connaissance, aucune donnée, à ce sujet n'a été publiée.

4.1.9 *Kampuchea.* Hora et Pillay (1962) signalent qu'il y avait au Kampuchea 1 400 000 ha de rizières irriguées, mais il n'y a aucune précision au sujet des pratiques de rizipisciculture.

4.1.10 *Malaisie.* La rizipisciculture extensive se pratique surtout sur la côte ouest de la Péninsule Malaise où existent des plaines alluviales et marécageuses. Des poissons envahissent les rizières, ils y grandissent et s'y reproduisent (Coche, 1967). Selon Hora et Pillay (1962) il y avait en Malaisie 45 500 ha de rizières irriguées avec élevage de poissons. Quand les rizières commencent à s'assécher, les poissons se retirent dans les drains et se retrouvent dans des viviers de 40–50 m^2 et de 2 m de profondeur (Soong, 1954).

L'espèce principale capturée est *Trichogaster pectoralis*, qui représente 70% du poids capturé dans les rizières de la côte ouest (Coche, 1967). Les autres espèces récoltées sont: *Anabas testudineus, Clarias batrachus, Ophiocephalus striatus* et *Trichogaster trichopterus.* Il y a également eu en Malaisie des essais d'élevage en rizières de *Tilapia mossambica,* mais ces essais n'ont pas donné de résultats à cause de la forte prédation exercée sur *T. mossambica* par *O. striatus* et *C. batrachus.*

La production moyenne de poisson atteint 135 kg/ha, en 6 à 10 mois d'élevage. Les productions varient de 10 kg à plus de 400 kg/ha, en fonction de la nature et de la fertilité des sols (Coche, 1967). Bien que cette production supplémentaire soit économiquement fort avantageuse, l'on a constaté depuis 1969 une nette régression des surfaces exploitées en rizipisciculture à la suite de l'introduction d'une nouvelle variété de riz permettant d'obtenir deux récoltes de paddy par an, de l'utilisation intensive d'insecticides et de la pratique d'assecs fréquents (Tan *et al*, 1973).

En 1973, le Ministère de l'Agriculture et des Pêches de Malaisie a entrepris, dans le District de Krian une étude afin de déterminer: (*a*) la production de poisson et de paddy des rizières irriguées et leur importance relative; (*b*) les types d'insecticides et l'étendue de leur utilisation en rizières ainsi que les effets de ces produits chimiques sur le peuplement piscicole. Le rapport de ce comité présente un grand intérêt et il contient des informations très précises sur la production de poisson et de paddy, la commercialisation, l'utilisation de divers insecticides et leur toxicité, le revenu des rizipisciculteurs, *etc.* Les principales conclusions peuvent se résumer comme suit (Tan *et al*, 1973):

(*i*) L'enquête a porté sur 1 230 ha où il y a double récolte de paddy par an et où se trouvaient 1 007 paysans ainsi que sur un autre bloc de rizières où se trouvaient 534 riziculteurs mais ne faisant qu'une seule récolte de riz par an. Quatre-vingt-et-un pour cent des surfaces empoissonnées ont été pêchées.

(*ii*) La production moyenne de poisson en rizières était de 132 kg/ha.

(*iii*) Les captures étaient composées de 72% de *Trichogaster pectoralis,* 20% de *Clarias macrocephalus,* 6% d'*Ophiocephalus striatus* et 2% d'*Anabas testudineus.*

(*iv*) La production moyenne des rizières avec double récolte de paddy était de 95,7 kg/ha contre 203,5 kg/ha dans les rizières avec une seule récolte de paddy par an.

(*v*) La production de 1971 n'atteignait que 40% de celle de 1969. Selon les paysans, cette forte diminution a été causé par l'utilisation d'insecticides et des assecs fréquent.

(*vi*) La production de paddy variait de 2 270 à 2 966 kg/ha.

(*vii*) Le revenu annuel net par ferme (superficie moyenne 1,10 ha) et le pourcentage du revenu annuel provenant du poisson par rapport à celui du paddy variaient comme suit (Tableau IV).

TABLEAU IV

	Fermier propriétaire		*Fermier à bail (60%)*	
	double récolte	*récolte unique*	*double récolte*	*récolte unique*
—revenu net annuel par ferme (US$)	762	366	393	184
—pourcentage du revenu annuel provenant du poisson	6%	27%	12%	52%

En vue d'arrêter le déclin de la rizipisciculture dans le District de Krian, les auteurs de cette étude recommandent les mesures suivantes:

(*i*) N'utiliser que les insecticides qui, aux doses habituelles, ne sont pas toxiques pour les poissons élevés en rizières (Sevin et Malathion par exemple).

(*ii*) Ne plus appliquer les insecticides par routine et par mesure prophylactique (ce qui est antiéconomique), mais seulement au moment où il y a de sérieuses présomptions que le riz sera attaqué par les borers ou par des insectes phytophages. Il n'est d'ailleurs pas certain qu'il est plus économique de lutter contre les insectes, plutôt que d'élever du poisson en rizières et perdre un certain pourcentage de paddy.

(*iii*) Maintenir dans la rizière un niveau d'eau entre 45 et 60 cm, même si cela n'est pas entièrement compatible avec les variétés de riz à croissance rapide. Dans ce cas, la production piscicole compensera vraisemblablement les inconvénients d'une plus grande profondeur d'eau et une diminution du rendement en paddy.

(*iv*) Augmenter les dimensions des drains et des trous-refuges pour remédier aux inconvénients des assecs indispensables aux productions élevées de paddy. La production de poisson compensera sans doute la perte de paddy.

(*v*) Vérifier quelle est, du point de vue de la santé publique, l'influence de l'application des produits phytosanitaires sur les populations de riziculteurs particulièrement exposées aux effets polluants de ces insecticides.

4.1.11 *Philippines.* La FAO (1958) signale des récoltes de poissons en rizières aux Philippines sans autres précisions. Dans la littérature consultée, nous n'avons pas trouvé de renseignements à ce sujet.

4.1.12 *Sri Lanka. Tilapia mossambica* y serait élevé en rizières (FAO, 1958). Selon Hora et Pillay (1962), il y avait à l'époque dans ce pays 350 000 ha de rizières irriguées. Aucun auteur ne précise quelles sont les superficies consacrées à la rizipisciculture et quelles sont les espèces de poisson utilisées.

4.1.13 *Thaïlande.* La superficie totale des rizières irriguées s'élevait en 1971 à 31 000 km^2 (Aubray et Isarankura, 1974). Des essais de rizipisciculture sont entrepris à la station de recherches de Khon Kaen. Les principales espèces utilisées en rizipisciculture sont: *Ophiocephalus striatus, Clarias batrachus, Cyprinus carpio, Anabas testudineus, Tilapia mossambica* et *Trichogaster pectoralis.*

Selon Swingle et Shell (1972) les paysans thaïlandais se méfient de la pratique d'élevage de poissons en rizières. Les raisons de cette méfiance sont notamment le danger de perdre le poisson lors des inondations ou de la sécheresse, les pertes par prédation et par vol et le surplus de travail qu'exige le creusement des drains et le renforcement des diguettes. Selon ces auteurs, c'est *Tilapia nilotica* qui a la préférence des paysans et des essais de rizipisciculture ont donné les résultats suivants avec des densités à la mise en charge des rizières de 18 à 30 alevins/are (optimum: 20 alevins/are): (*i*) rendement moyen sans nourriture: 210 kg de poisson/ha; (*ii*) rendement moyen avec nourriture: 250 kg de poisson/ha; (*iii*) rendement de riz en rizipisciculture: 1 200 à 1 500 kg de paddy/ha; (*iv*) en rizières fertilisées avec alimentation supplémentaire (son de riz, riz concassé et *Hydrilla*) la production avec la carpe commune atteint 418 kg/ha.

4.1.14 *Viet Nam.* Coche (1967) signale que l'on pratique la rizipisciculture avec la carpe commune dans les régions montagneuses du pays Thaï. Les rizières sont mises en charge en avril, à la densité de 20 000 alevins/ha. Une première récolte, après 3 mois, donne 80 à 100 kg/ha de poisson de 40–50 g. Si on récolte après 6 ou 7 mois (octobre) la production est de 100 à 150 kg/ha pour des carpes de 60 à 150 g.

Dans les régions deltaïques et basses du Viet Nam, le climat tropical permet de faire une culture sur 5 mois (janvier-mai) ou deux récoltes par an. On utilise surtout la carpe commune et parfois *Tilapia mossambica* (Cao-Thien-Buu, 1958). Se trouvent également en rizières: *Clarias batrachus, Ophiocephalus striatus* et *Trichogaster pectoralis.* Ces espèces sont capturées en rizipisciculture extensive.

4.2 *Afrique*

La situation de la rizipisciculture en Afrique a été décrite récemment par Vincke (1976). Dans dix pays africains il n'y a eu que des essais de rizipisciculture, notamment au Cameroun, en Côte d'Ivoire, en Egypte, au Gabon, au Kenya, au Libéria, en Empire centrafricain, en Rhodésie, en Zambie et au Zaïre. Malgré ces essais et le fait que plusieurs pays africains ont manifesté leur intention de développer la rizipisciculture comme un moyen d'améliorer la ration alimentaire des habitants de certaines régions, la rizipisciculture ne s'est pratiquement pas développée en Afrique, à l'exception de Madagascar. Quatre cas sont examinés ci-après.

4.2.1 *Côte d'Ivoire.* Les essais entrepris en 1963–65 à Korogo par Stiemer, expert FAO, affecté à la SODERIZ, étaient considérés comme un moyen pratique pour promouvoir une meilleure maîtrise de l'eau dans les rizières (diguettes plus larges et plus hautes, planage plus correct, *etc*). En général, et selon les renseignements obtenus sur place, les rizières empoissonnées étaient plus soignées et les aménagements étaient meilleurs. Les résultats ont cependant été très hétérogènes et seuls les résultats des essais de 1965 sont disponibles.

A des densités comprises entre 20 et 80 alevins/are en monoculture, et pour une durée d'élevage approximative de 100 à 120 jours, les rendements en poisson étaient les suivants (Vincke, 1976): (*i*) *Heterotis niloticus:* 139 kg/ha/an avec des poids moyens allant de 62 à 233 g (*ii*) *Tilapia nilotica:* 44,5 kg/ha/an. Poids moyens à la récolte entre 19 et 105 g (*iii*) *T. macrochir:* 37,7 kg/ha/an. Poids moyens à la récolte entre 13 et 30 g.

4.2.2 *Gabon.* Six essais de rizipisciculture ont été conduits au Centre Piscicole National d'Oyem en 1971–72, mais seulement un essai est à prendre en considération, les autres ayant été soit négligés, soit arrêtés brutalement par des inondations, suivies de la perte totale des poissons. En polyculture *Tilapia nilotica* (1 alevin/m^2) + géniteurs *T. rendalli* (1 couple à l'are) + *Heterotis niloticus* (0,9 alevin pour 10 m^2), on a obtenu après 6 mois d'élevage en rizière, un rendement de 680 kg de poisson à l'hectare/an, avec des *Tilapia* marchands de 56 g. Il n'y a pas de renseignements précis sur les *Heterotis* et il se confirme que *T. rendalli* est un bon sarcleur, du moins lorsque le niveau de l'eau est suffisant pour permettre aux poissons de circuler entre les plants.

4.2.3 *Libéria.* A partir de 1971 quelques essais de rizipisciculture ont été entrepris à la Station Centrale d'Expérimentation Agricole de Suakoko, par la Division des Pêches, conjointement avec le projet FAO/PNUD Développement de la Riziculture au Libéria (Vincke, 1972a).

Quatre parcelles fertilisées, sans drain ni trou-refuge ont été mises en charge avec *Tilapia macrochir*, 56 jours après le repiquage, à la densité de 4 952 alevins/ha. Le poids moyen des alevins variait entre 10 et 26 g. Durant l'essais, il n'y a pas eu d'application de produits phytosanitaires et il n'y a eu qu'un seul sarclage manuel. Les poissons n'ont reçu aucune alimentation supplémentaire. Les traitements appliqués étaient les suivants: 2 rizières avec poissons, une avec du riz mais sans poissons, une avec poissons mais sans riz. Durant l'essai il y a eu vol de poissons, et l'on a constaté que

des poissons étaient passés d'une parcelle à l'autre par des trous dans les diguettes. Le riz a été récolté 166 jours après la repiquage, sans assec des rizières, et les poissons n'ont pas été récoltés. On a repiqué du riz une seconde fois dans les mêmes parcelles. Ainsi les poissons ont séjourné 238 jours en rizière.

Les résultats de cet essai étaient les suivants (Vincke, 1972a): (*i*) parcelles avec riz + poissons: 234 kg et 282,7 kg de poisson/ha/an + 61 et 71 kg/ha de paddy. (*ii*) parcelle avec riz seul: 56,79 kg de paddy/ha/an. (*iii*) parcelle avec poissons seul: 102,8 kg de poisson/ha/an.

Malgré les circonstances qui ont quelque peu faussé cet essai, les résultats obtenus sont intéressants. A noter que fin 1972 on estimait que la superficie totale des rizières irriguées au Libéria atteignait 626 ha où la rizipisciculture pourrait être pratiquée.

4.2.4 *Madagascar*. La rizipisciculture extensive existe à Madagascar depuis le début des années 1900, mais elle n'a réellement connu un certain succès qu'à partir de 1920, surtout sur les Hauts-Plateaux. A partir de 1925–26, la carpe miroir (*Cyprinus carpio* var. *specularis*) s'est répandue et, petit à petit, a remplacé les espèces utilisées précédemment en rizières (*Carassius auratus* et *Eleotris legendrei*).

L'élevage de poissons en rizières n'a pratiquement pas connu d'extension jusqu'en 1962. C'était resté un élevage extensif, à l'exception de la région de Betafo (Antsirabe) où, en 1953, il y avait 16 ha de rizières dans lesquelles ou élevait des carpes miroir. De 1962 à 1973, la Division de Recherches Piscicoles du Centre Technique Forestier Tropical a exécuté un programme de recherches tendant à mettre au point les techniques d'élevage de poissons en rizières (Vincke, 1973).

Durant ces essais l'on a testé les espèces suivantes: carpe commune var. royale *Tilapia zillii, T. nilotica, T. mossambica, T. macrochir, T. rendalli, Paratilapia polleni, Carassius auratus, Micropterus salmoides* et *Heterotis niloticus*. Ces essais ont porté sur la densité à la mise en charge en monoculture et en polyculture, l'influence des aménagements piscicoles préconisés en rizières (drain périphérique et trou-refuge), l'application d'engrais et de produits phytosanitaires (Lindane) durant l'élevage, l'alimentation supplémentaire des poissons et les élevages complémentaires, après la récolte du riz.

Rabelahatra (1972) a dressé le bilan des recherches sur la rizipisciculture effectuées à Madagascar et ses conclusions peuvent se résumer comme suit:

(*i*) La réussite de la rizipisciculture dépend essentiellement de la maîtrise de l'eau, de l'état des diguettes, des aménagements piscicoles de la rizière (drain périphérique, trou-refuge, entrées et sorties d'eau, *etc*), de la fumure, du choix des espèces à élever en rizières, de la disponibilité et de l'approvisionnement régulier en alevins.

(*ii*) La mise en charge des rizières peut se faire à partir de la deuxième semaine après le repiquage. Les densités d'empoissonnement préconisées sont les suivantes: (*a*) carpe commune var. royale seule: 25 alevins/are; (*b*) *Tilapia* seul (*T. nilotica, T. macrochir, etc*): 15–30 alevins/are; (*c*) Polyculture = carpes 25/are + poissons d'accompagnement: 25/are.

(*iii*) dans de bonnes conditions et après un élevage en rizières en 120–140 jours, l'on obtient entre 150 et 200 kg de poisson à l'hectare de rizières, valant entre F.MG. 75 et 20 000 (F.MG. 250 = US$ 1 en 1971–1972).

Si l'on aménageait convenablement les 175 000 ha de rizières à adduction d'eau contrôlée, où la rizipisciculture est possible, l'on pourrait obtenir 35 000 tonnes de poisson durant le cycle cultural du riz irrigué.

Jusqu'au début des années 1960, le développement de la rizipisciculture à Madagascar a été très lent. En 1960, la production piscicole des rizières était évaluée à 15 tonnes (Vincke, 1972). L'obstacle majeur à l'extension de cet élevage reste toujours la pénurie d'alevins, notamment des carpillons de souches sélectionnées. Les dernières années, les superficies consacrées à la rizipisciculture n'ont cependant fait qu'augmenter à un taux annuel de 12 à 15% du fait d'un meilleur encadrement des cultivateurs et parce que l'on a pu mettre à leur disposition les alevins de carpe royale nécessaires.

En 1971, l'on estimait qu'il y avait 411 ha consacrés à la rizipisciculture, donnant 82 tonnes de poisson valant F.MG. 8 220 000 (Vincke, 1972b). Il est évident qu'il y a encore d'énormes possibilités d'extension de la rizipisciculture à Madagascar. Cette extension suppose un encadrement des paysans et l'augmentation des capacités de production des stations d'alevinage de l'île (Vincke, 1976).

4.3 *Amériques*

En Amérique du Nord une certaine forme de rizipisciculture est pratiquée aux Etats-Unis. Il y a eu également quelques essais en Haïti, au Brésil, en Guyane et en Argentine (Coche, 1967).

4.3.1 *Etats-Unis d'Amérique*. La pisciculture en rizières y a débuté vers 1950 et beaucoup de problèmes restent à résoudre. Cette pisciculture en rizières semble relever bien plus de techniques de mise en valeur et de défrichement de terres incultes et d'opérations de jachère que de rizipisciculture. Comme le signale Coche (1967) l'on utilise l'eau dans deux cas précis: défrichement par inondation de terrains boisés incultes, et mise en jachère de rizières irriguées pour leur rendre une certaine fertilité, éviter l'érosion et éliminer des plantes adventices qui concurrencent le riz.

D'après Johnson et Davison (1958), la riziculture aux Etats-Unis d'Amérique est fortement mécanisée et quelques hommes suffisent à cultiver plusieurs centaines d'hectares. Des rizières d'une trentaine d'hectares ne sont pas rares.

Les rizières produisent moins de paddy au fur et à mesure qu'elles sont envahies par les plantes adventices aquatiques telles que *Echinochloa* et *Panicum*, car il y a concurrence avec le riz pour les éléments nutritifs du sol, l'espace et la lumière (Johnson et Davison, 1958). Ailleurs dans le monde, où la riziculture n'est pas une entreprise mécanique gigantesque, ces problèmes ont été résolus par le sarclage manuel ou par l'emploi d'herbicides sélectifs. Aux Etats-Unis d'Amérique l'on applique une jachère pour obtenir les mêmes résultats. Jadis les rizières en jachère étaient transformées en pâturages ou en champs de soja. Maintenant elles restent sous eau et on y fait de la pisciculture. Les espèces utilisées sont *Ictiobus cyprinellus, Ictalurus punctatus, Cyprinus carpio* et *Micropterus salmoides* (Huet, 1970). Généralement les poissons restent en rizières durant toute la durée de la jachère. La production moyenne est de 119 kg/ha/an (Coche, 1967).

4.3.2 *Amérique Centrale et du Sud.* La pisciculture en rizières y est peu développée. En Haïti il y a eu quelques essais avec la carpe commune et divers *Tilapia.* Au Brésil, dans la vallée du Paraiba, l'on a testé *Cyprinus carpio* et *Tilapia rendalli* en monoculture et en polyculture. Le but de ces essais était de vérifier l'action des poissons sur le riz et les plantes adventices. En moyenne on a récolté entre 166 et 562 kg de poisson/ha et les poissons n'ont causé aucun dégât aux plants de riz (Coche, 1967).

Selon Macdonagh (1946), il y a très peu de rizipisciculture en Argentine. L'espèce principale est *Odontesthes bonariensis* dont la croissance et la reproduction ont été satisfaisantes dans des conditions expérimentales. Les moustiques ont été éliminés durant ces essais.

4.4 *Europe*

La rizipisciculture a été pratiquée à petite échelle dans quelques pays d'Europe, notamment en Bulgaria, Espagne, Hongrie et Italie. Dans ce dernier pays, les essais sont restés sans suite.

4.4.1 *Bulgarie.* Selon Coche (1967) et Huet (1970), l'on fait de la rizipisciculture en Bulgarie, du moins à titre expérimental, en utilisant la carpe commune.

4.4.2 *Hongrie.* Coche (1967) signale que dans ce pays, la riziculture irriguée couvre 45 000 ha. Des rotations et une irrigation adéquate ont permis des récoltes de paddy atteignant 2 200 kg/ha. Ce sont surtout les coopératives et les fermes d'état qui pratiquent la rizipisciculture, en utilisant la carpe commune, et dans le but de réduire leurs coûts de production, les carpes sont élevées en rizière durant la culture du riz de mai à septembre. A la récolte, les carpillons ont une taille moyenne de 20 cm et ils sont transférés pour grossissement dans les étangs de fermes situées à proximité des rizières. En l'absence de poissons marins, les poissons d'eau douce, notamment les carpes, atteignent un bon prix, le poisson étant considéré comme un produit alimentaire important. La carpe semble contribuer au maintien de bonnes conditions dans les rizières.

4.4.3 *Italie.* La rizipisciculture intensive a été introduite dans le nord de l'Italie (plaine de Lombardie et vallée du Pô) à la fin du 19ème siècle, d'après Tonolli (1955). Très rapidement et surtout à partir de la guerre 1940–45, les riziculteurs ont pratiquement abandonné ce type d'élevage du fait de certaines difficultés techniques (rehaussement des digues, augmentation des quantités d'eau d'irrigation, *etc*) et économiques (Hickling, 1962; Coche, 1967). L'espèce principale est *Cyprinus carpio*, très souvent associée à *Carassius auratus* et à *Tinca tinca.* Actuellement, il reste quelques fermiers qui, en rizières, produisent des fingerlings qu'ils revendent ensuite à des propriétaires d'étangs et à des sociétés de pêche.

4.5 *Bilan et conclusions*

Dans les pays à riziculture très évoluée, l'aquaculture en rizières est en régression, notamment en Asie et en Europe. Cette situation est due à l'introduction de variétés de riz à rendement élevé et généralement à tige courte exigeant une mince lame d'eau, à l'emploi de produits phytosanitaires et d'herbicides toxiques pour les animaux aquatiques et enfin à le possibilité de faire deux cultures par an.

Il apparait que l'Afrique est le continent où l'aquaculture en rizières a le plus de chances de se développer dans un proche avenir si les projets d'aménagement de vastes rizières irriguées sont mis à exécution. Jusqu'à présent, les services intéressés n'avaient pas réalisé pleinement les possibilités d'accroissement piscicole qu'offre la rizipisciculture.

5 Perspectives et avenir de l'aquaculture en rizières dans le monde

La pénurie croissante de protéines animales surtout dans les pays en voie de développement conduit à penser que la rizipisciculture se développera dans les pays où la riziculture irriguée existe ou est en train de s'implanter. Cette méthode culturale ne doit pas être considérée seulement comme une source de profits mais surtout comme un moyen d'assurer l'apport de protéines animales à des fermiers qui se trouvent dans l'incapacité de se les procurer autrement. Il faut de plus relever que la rizipisciculture peut aussi contribuer à l'augmentation de la production de paddy ainsi qu'à l'amélioration de l'environnement en réduisant l'emploi de produits phytosanitaires toxiques.

Il y a dans le monde plus de 35 millions d'hectares de rizières irriguées dont 30% environ pourraient produire du poisson (Pillay, 1973). Si les renseignements sont relativement abondants pour la région Indo-Pacifique, les données essentielles pour faire le point de la situation font défaut pour les autres régions.

L'emploi intensif d'engrais chimiques favorise la croissance du riz, mais les produits sont souvent toxiques pour les poissons et incompatibles avec des élevages en rizières (Hickling, 1962). Il en est de même avec certains herbicides sélectifs et des insecticides. Au Japon, il est plus économique d'utiliser des moyens chimiques et augmenter ainsi la récolte de riz que d'avoir une récolte supplémentaire de poisson avec une plus faible récolte de paddy (Hickling, 1962). La situation paraît être la même en Chine (Province de Taiwan) et en Malaisie.

Dans certaines régions d'Afrique où se pratique déjà la riziculture irriguée et où existent des possibilités d'introduire la rizipisciculture intensive avec des chances de succès, il paraît indispensable de mettre en oeuvre des programmes de recherches appliquées basées sur les données obtenues à Madagascar (Vincke, 1976). La culture du riz étant nouvelle sur le continent africain, l'introduction simultanée de cette double technique de riziculture et de pisciculture en rizières semble difficilement assimilable par les paysans. La riziculture prend de plus en plus d'extension en Afrique; lorsqu'elle sera bien ancrée dans les moeurs, on peut espérer y associer l'élevage du poisson. Coche (1967) estime qu'il ne faut pas pousser les paysans africains à faire de la rizipisciculture intensive avant qu'ils aient acquis une certaine expérience des pratiques culturales du riz et de la conduite de l'irrigation.

Il paraît assez vraisemblable que l'aquaculture en rizières ne se développera plus en Europe pour les raisons citées plus haut. Il est difficile de statuer à ce sujet. Par contre, an Amérique du Nord et plus particulièrement aux Etats-Unis, les méthodes de culture et d'élevage seront améliorées et la pisciculture en rizières se développera sans doute dans certains états. En Amérique Latine les données disponibles sont trop rares pour se faire une idée claire de la situation. Dans ces pays où le besoin urgent existe d'augmenter la ration de protéines animales, la rizipisciculture paraît être

une des sources d'approvisionnement permettant de mieux nourrir les populations locales étant donné qu'on enregistre un certain développement de la pisciculture en étangs.

Le développement de la rizipisciculture dans le monde est subordonné à la connaissance pour chaque pays des éléments de base suivants (Vincke, 1976): (*i*) inventaire détaillé des surfaces de riziculture irriguées; (*ii*) situation des techniques culturales rizicoles actuellement mises en oeuvre: aménagement des rizières irriguées, hauteur des diguettes, maîtrise et alimentation en eau, sarclages (fréquences et méthodes appliquées), récolte du riz, *etc*; (*iii*) compte-rendu détaillé des essais d'aquaculture en rizières déjà réalisés; (*iv*) description des techniques piscicoles utilisées dans les rizières: espèces, tailles et poids moyens à la mise en charge, densité d'empoissonnement, durée d'élevage, récolte, *etc*; influence sur les animaux en rizières de l'utilisation de fertilisants, d'herbicides et de produits phytosanitaires; (*v*) inventaire des maladies et insectes s'attaquant au riz ainsi que des insecticides, fongicides et herbicides utilisés; (*vi*) catalogue des variétés de riz cultivées en rizières irriguées et renseignements pertinents tels que hauteur d'eau idéale pour obtenir les meilleurs rendements en paddy, tolérances vis-à-vis d'une hausse du niveau préconisé, *etc*; (*vii*) données économiques concernant le paddy et le poisson récoltés en rizières irriguées; (*viii*) inventaire complet et détaillé des projets de programme de développement ou d'extension de la riziculture irriguée, ainsi que les possibilités d'y intégrer la rizipisciculture.

Ces données, aussi complètes que possible, nous paraissent indispensables à l'établissement d'un nouveau bilan de l'aquaculture en rizières dans le monde. Dans une première phase, et pour combler en partie les lacunes de la littérature, l'on pourrait rassembler les données disponibles dans les dossiers des Bureaux Régionaux FAO. L'on pourrait envisager ensuite la création d'un groupe de travail par correspondence.

Ce bilan permettrait de faire le point de la situation de la rizipisciculture dans le monde et d'élaborer, à une échelle régionale ou sous-régionale, un programme de recherches en vue de promouvoir la rizipisciculture dans les régions où elle pourrait contribuer efficacement à réduire les carences en protéines animales, tout en apportant aux ruraux des revenus monétaires non négligeables. Dès maintenant il apparaît que ces programmes de recherches devraient au moins comprendre l'étude des points suivants: (*i*) économie des différentes méthodes d'aquaculture en rizières, en tenant compte de tous les facteurs, afin de démontrer sa rentabilité financière; (*ii*) influence sur les poissons élevés en rizières et sur les humains de l'utilisation des produits phytosanitaires, afin de compléter les recherches déjà effectuées en ce domaine dans divers pays. Etudier également les effets résiduels de ces produits; (*iii*) recherche de nouvelles espèces piscicoles adaptées à l'élevage en rizières et essais d'utilisation de poissons malacophages comme moyen de lutte contre la bilharziose; (*iv*) poursuite des recherches concernant l'élevage de crevettes en rizières, ainsi que la mise au point de différents types de polycultures; (*v*) de nouveaux essais concernant les densités à la mise en charge et l'influence de l'alimentation supplémentaire des poissons élevés en rizières et l'utilisation d'engrais vert.

Enfin, il est indispensable d'attirer l'attention sur les deux facteurs qui peuvent freiner considérablement le développement de la pisciculture en rizières: le manque de personnel de vulgarisation et la pénurie d'alevins. Pour garantir le succès des programmes de rizipisciculture, un service de vulgarisation et d'encadrement compétent est indispensable. Des stations d'alevinage bien équipées doivent être à même de ravitailler les rizipisciculteurs en alevins des espèces préconisées.

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Rice-Fish Culture and the Green Revolution

John H. Grover

Abstract
The culture of rice and fish together can potentially increase and stabilize income on rice farms even when technology of the Green Revolution is applied. Yield trials with rice-fish culture are being conducted at the Freshwater Aquaculture Center in the Philippines using newly developed, insect-resistant, high-yielding rice varieties. Four trials completed during 1974–75 indicate that good rice production can be obtained without insecticide applications. *Tilapia mossambica* and *Cyprinus carpio* stockings have resulted in standing crops of fish in rice paddies averaging 69 to 208 kg/ha at harvest time.

La rizipisciculture et la révolution verte
Résumé
La culture du riz associée à la pisciculture est susceptible d'accroître et de stabiliser les revenus des riziculteurs, même lorsque la technologie de la révolution verte est appliquée. Des essais de rendement rizipiscicole sont en cours au Centre d'aquaculture dulcaquicole des Philippines avec des variétés de riz récemment mises au point, résistantes aux insectes et à haut rendement. Quatre essais en 1974–75 indiquent qu'il est possible d'obtenir une bonne production de riz sans appliquer d'insecticides. L'empoissonnement avec *Tilapia mossambica* et *Cyprinus carpio* a donné des biomasses de l'ordre de 69 à 208 kg/ha dans les rizières, au moment de la récolte.

El cultivo de arroz y peces y la revolución verde
Extracto
El cultivo conjunto de arroz y peces puede aumentar y estabilizar los ingresos de las explotaciones arroceras incluso cuando se aplica la tecnología de la Revolución Verde. En el Centro de Acuicultura de Agua Dulce de las Filipinas se están realizando ensayos sobre el rendimiento del cultivo de arroz y peces utilizando variedades de arroz recién desarrolladas resistentes a insectos y de gran rendimiento. Los cuatro ensayos completados durante 1974–75 indican que puede obtenerse una buena producción de arroz sin aplicar insecticidas. Siembras de *Tilapia mossambica* y *Cyprinus carpio* en los arrozales han producido rendimientos promedios de 69 a 208 kg/ha en el momento de la cosecha

1 Introduction

Culturing fish and rice together is an old practice that has been well reviewed by Ardinawata (1958), Hora and Pillay (1962) and Coche (1967). This system gives farmers added income and diversified harvest. There is also some evidence that the presence of fish increases rice yields when traditional farming methods are used. However, interest in producing rice and fish together has declined in recent years because of the large amounts of fish-toxic insecticides necessary to protect the high yielding rice varieties introduced as part of the 'Green Revolution' in Asia. Now, newer high yielding rice varieties are being developed with inbred resistance to insects and insect-transmitted diseases. This decreases the need for insecticide protection of growing rice. At the Freshwater Aquaculture Center in Muñoz, Philippines, experiments are being conducted to evaluate methods of combining fish culture with farming of these newest rice varieties.

The high yielding rice varieties have new characteristics which may change some of the concepts associated with the old rice-cum-fish culture techniques. For example, traditional rice varieties usually take approximately 160 days to reach maturity and can tolerate relatively deep water. The latest high yielding varieties mature in 105 to 125 days allowing less time for the culture of fish in the paddy. The new varieties are mostly short-stemmed, shallow-water plants which can tolerate only moderate water depths not much in excess of 20 cm. Such shallow water does not favour production of larger fish preferred in some localities. However, the International Rice Research Institute (1975) has reported significant efforts to improve deep-water (floating) rice varieties. Modern rice varieties receiving recommended amounts of fertilizer probably will benefit less from fish activity in the paddies than traditional varieties although in either case fish may eat some of the undesirable insects including mosquitoes. Spiders which eat destructive insects are also more numerous in rice when no insecticides are used. Certainly, it is ecologically more desirable to have biological rather than chemical control of insect pests.

There are also advances in fish culture which need to be evaluated in rice field situations. Production yields of all-male stocks of *Tilapia mossambica* are being tested at the Freshwater Aquaculture Center. The males grow faster than females and, if stocked alone, can not reproduce. Chemically sex-reversed stock are also being tested to determine if reproduction control and growth is better than with manually sexed stocks. Traditional ideas about stocking rates and growth expectations need to be adjusted to the short-season, shallow-water, high-fertilizer conditions in modern rice fields. There is also a need to explore the use of rice fields as hatcheries or nurseries for pond stock and the possibility of stock rotation to produce optimum-size fish for the market.

Culturing fish with rice does create added costs which need to be offset by the fish production. More water is needed and the water must be regulated to prevent escape of fish or entry of unwanted wild fish. Water quality must be tolerable for fish and fish food organisms, and paddy dikes need to be stronger and higher than normal to contain fish and water. Usually some of the rice production area is made into a trench where fish can find refuge when they are not foraging among the rice plants. These trenches also serve as capture channels in which the fish collect when water is

lowered. These many factors must be considered in evaluating the economics of modern rice-fish culture.

2 Experimental results

Four yield trials with rice-fish culture using the new rice variety IR26 have been completed. Government-recommended procedures for rice farming were used except that no insecticide applications were made and there was a trench in each plot. Yields of IR26 grown in these insecticide-free trials exceeded production of other varieties grown in surrounding areas and a typical yield of unmilled rice was approximately 3 000 kg/ha. No clear relationship between rice and fish yields was apparent.

The first trial was conducted from January to June 1974 in five 800 m^2 plots created in dried pond bottoms. *Tilapia* sp., common carp (*Cyprinus carpio*) and catfish (*Clarias macrocephalus*) fingerlings were stocked in the plots to determine yields of each species. The total stocking weight was approximately 30 kg/ha. Standing crops at harvest averaged 130 kg/ha for fish. *Tilapia* yielded the greatest weight but this was because of reproduction resulting in many small fish. *Cyprinus carpio* had an average standing crop at harvest of 42 kg/ha with only 53% of the fish being recovered. *Clarias macrocephalus* did not grow well and only 29% were recovered.

The second trial was in 180 m^2 plots with fish stocked in April and harvested in July 1974. Nine plots were stocked with fish believed to be *Tilapia mossambica*, but subsequent identification determined that *T. zillii*, a new species in the Philippines, were also mixed in the stock. Stocking rates averaged 30 kg/ha. Standing crops of fish at harvest averaged 186 kg/ha. Small tilapia less than 15 g each, resulting from reproduction, accounted for 65% of the harvest weight.

The third trial compared production of monosex male *T. mossambica* at two stocking densities and with two trench designs. Twelve 200 m^2 plots were used with three replicates for each treatment. Fish were sexed by visual examination of the genital papillae and stocked at approximately 25 and 50 kg/ha. One trench system was a single ditch across the centre of the plot comprising 10% of the production area. The other trench system was a peripheral ditch comprising 23% of the production area. Fish were stocked in September and harvested in early December 1974. Fish harvest results are summarized in Table I. Recovery of stocked fish averaged 71%, and there was no increase in production in ponds with the larger trench system. Larger standing crops and greater net production results from the higher stocking rate. Stocked fish at harvest averaged 40 g at the lower stocking density and 34 g at the higher stocking density.

TABLE I
STANDING CROPS OF MALE *T. mossambica* HARVESTED AFTER 84 DAYS FROM RICE-FISH PLOTS WITH TWO TRENCH SYSTEMS

Stocking rate	*Production (kg/ha)*		
	Area of trench system		*Mean*
	10%	*23%*	
25 kg/ha	42·1	46·2	44·2
50 kg/ha	114·7	73·5	94·1
Mean	78·4	59·9	69·2

Trial four compared production of *Cyprinus carpio* and male *Tilapia mossambica*, each stocked at 30 kg/ha in separate 800 m^2 plots from February to June 1975. *C. carpio* grew from an average of 47 g to 237 g with 85% recovery and the standing crop at harvest was 208 kg/ha. Male *T. mossambica* grew from 35 g to 80 g with 100% recovery and had a standing crop at harvest of 89 kg/ha.

These results have been so encouraging that the experimental area of the Freshwater Aquaculture Center has been expanded to more than 40 operational plots covering more than one hectare. Co-operative demonstrations are being conducted with the National Irrigation Administration to determine the economics of fish production on a commercial scale. Current experiments are designed to compare yields of several species of fish at various stocking rates, and other rice varieties are being evaluated. The effects of different fertilizers, water regimes and supplemental feeding are also scheduled for testing.

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The Economics of Various Management Techniques for Pond Culture of Finfish

H. R. Rabanal and Y. C. Shang

Abstract

On a worldwide basis, pond culture of finfish produces about 75% of the production in weight and utilizes about 90% of the area devoted to aquaculture. It is estimated that it has stimulated a capital expense investment of about US$ 3 500 million. The potential for increasing aquaculture production through expanding pond culture of finfish is high.

An analysis is made of the economics of finfish pond culture in order to: (*i*) establish improved management practices that will make the industry more profitable; and (*ii*) guide the formulation of policies and programmes which affect development of the aquaculture industry.

The species considered in this study are; milkfish, common carp, Chinese carps, Indian major carps, catfishes (channel, *Clarias*, pangasid), tilapia, grey mullet, eel and rainbow trout.

The profitability of the use of monoculture versus polyculture and the use of extensive versus intensive techniques are explored with respect to a number of these species.

There are many factors affecting the profitability of pond culture. The rate of return on investment is bound to vary according to local conditions. The experiences achieved by many countries on various species indicate that, in general, intensive operation increases the productivity and reduces the cost of production per unit of output; and polyculture earns more profit than monoculture.

Seed, fertilizer, feed, labour, marketing and interest constitute the major cost items of pond culture operations, and research on reduction of these costs is of high priority.

The economic profitability of aquaculture can be improved not only by increasing productivity and reducing production cost, but also by improving prices received by pond operators. This can be achieved by initiating improvements in the quality of fish and by better marketing strategy and channels.

Aspects économiques de diverses techniques d'aménagement propres à la pisciculture en étang

Résumé

Au plan mondial, l'élevage des poissons en étang représente en poids quelque 75% de la production de l'aquaculture et utilise environ 90% de la superficie qui lui est consacrée. On estime que cette activité est à l'origine d'un investissement de capital atteignant quelque US$ 3 500 millions. Le potentiel d'accroissement de la production aquicole est élevé grâce à l'expansion de l'élevage des poissons en étang.

L'analyse économique de l'élevage des poissons en étang vise les objectifs suivants: (*i*) mettre au point des méthodes de mise en valeur améliorées qui rendront l'industrie plus profitable; et (*ii*) guider l'élaboration de politiques et de programmes qui affectent le développement de l'industrie aquicole.

Ci-après les espèces sur lesquelles porte cette étude: chanidés, carpe commune, carpes chinoises, principales carpes indiennes, poissons chats (ictalure, *Clarias*, pangasidés), tilapia, mulet gris, anguille et truite arc-en-ciel

Le document étudie la rentabilité de la monoculture par comparaison avec la polyculture, et l'utilisation des techniques extensives à l'encontre des techniques intensives pour un certain nombre d'espèces.

De nombreux facteurs influent sur la rentabilité de l'élevage en étang. Le rendement des investissements varie inévitablement en fonction des conditions locales. D'après les expériences menées par maints pays avec diverses espèces, il semble qu'en général les opérations intensives accroissent la productivité et réduisent le coût de production par unité; par ailleurs, la polyculture permet de réaliser plus de bénéfices que la monoculture.

Les principaux postes des operations d'élevage en étang sont les reproducteurs, les engrais, les aliments, la main-d'oeuvre, la commercialisation et le loyer de l'argent, et il est impérieux d'effectuer des recherches sur les moyens de reduire ces coûts.

Il est possible d'améliorer la rentabilité économique de l'aquaculture non seulement en accroissant la productivité et en réduisant les coûts de production, mais aussi en rehaussant le niveau des prix dont bénéficient les exploitants des étangs. L'on peut y parvenir en apportant des améliorations à la qualité du poisson et en perfectionnant la stratégie et les réseaux de commercialisation.

Aspecos económicos de distintas técnicas para el manejo del cultivo de peces en estanques

Extracto

Del cultivo de peces en estanque procede cerca el 75% de la producción mundial de la acuicultura en peso, y a él se dedica cerca del 90% de la superficie explotada para la acuicultura. Se calcula que este cultivo ha estimulado inversiones de capital del orden de US$ 3 500 millones. Las posibilidades de aumentar la producción acuícola incrementando el cultivo de peces en estanques son elevadas.

Se analizan los aspectos económicos del cultivo de peces en estanques a fin de: (*i*) establecer mejores sistemas de manejos prácticos, que permitan obtener mayor rentabilidad de esta industria; y (*ii*) dar orientaciones para la formulación de politicas y programas para el desarrollo de la industria acuícola.

Las especies que se han tenido en cuenta en este estudio son: sabalote, carpa común, carpas chinas, principales carpas indias, bagres (de canal, *Clarias, Pangasius*), tilapia, múgil, anguila y trucha arco-iris.

Se examina, en relación con varias de estas especies, la rentabilidad del monocultivo y del policultivo asi como del empleo de técnicas extensivas o intensivas.

Son muchos los factores que influyen en la rentabilidad del cultivo en estanques. El porcentaje de beneficios sobre las inversiones no puede por lo menos depender de la situación local. La experiencia lograda en muchos países con diversas especies indica que, en general, con el cultivo intensivo se aumenta la productividad y se reducen los costos de producción por unidad y que el policultivo resulta más rentable que el monocultivo. Los principales conceptos de gasto en la piscicultura en estanques son las semillas, los fertilizantes, los piensos, la mano de obra, el mercadeo y los intereses, por lo que ha de concederse alta prioridad a las investigaciones tendientes a reducir estos costos.

La rentabilidad económica de la acuicultura puede mejorarse no sólo incrementando la productividad y reduciendo los costos de producción sino también mejorando los precios percibidos por los piscicultores. Esto último puede lograrse comenzando a mejorar la calidad del pescado y con mejoras en la estrategia y canales de mercadeo.

1 Introduction

Pond culture for finfish, utilizing either freshwater, brackishwater, or marine situations, is the most widely practised type of operation in aquaculture.

It is estimated that 3·7 million tons or 75% of the world production through aquaculture, covering 2·3 million ha or 90% of the total area used for aquaculture, is derived from this type of system. It is also estimated that pond culture for finfish has stimulated an investment for capital expenses equivalent to US$ 3 500 million. Furthermore, the potential for increased production from this sector is very high (Ling, 1973). It is estimated, for example, that in southeast Asia alone there are about 22 million ha suitable for development of ponds for finfish culture.

The object of this paper is to analyse the economics of this well established and economically viable form of culture. It is hoped that this analysis will aid in: (*i*) finding methods of improved management that will make the industry more profitable; and (*ii*) guiding the formulation of policies and programmes which affect its development.

Data for this type of study are extremely limited and often difficult to obtain. The economics of only those species of finfish for which data are readily available to the authors are treated in this paper.

The species of finfish discussed here are listed on the bottom of this page.

The species first listed, milkfish, is raised commercially in Indonesia, the Philippines, and Taiwan Province of China. Common carp culture is widely practised in Europe, Israel, Japan and mainland China as monoculture. The use of the herbivorous/omnivorous Chinese carps with common carp in polyculture is practised in some European countries as well as in southeast Asia. Polyculture using the Indian major carps is common in India and neighbouring countries where these species are indigenous. The ictalurid channel catfish is an important commercially-cultured fish in the United States. Clariid and pangasid catfishes are raised intensively in Thailand and their culture is spreading in southeast Asia.

Other widely cultivated warmwater fish are the tilapias cultivated not only in their native areas, Africa and the Middle East, but also in the Asiatic part of the USSR, parts

Common name	*Scientific name*	*Family name*
Milkfish	*Chanos chanos*	Chanidae
Common carp	*Cyprinus carpio*	Cyprinidae
Chinese carps		
Grass carp	*Ctenopharyngodon idella*	"
Silver carp	*Hypophthalmichthys molitrix*	"
Bighead	*Aristichthys nobiles*	"
Indian major carps	Various species	"
Catfishes		
Channel catfish	*Ictalurus punctatus*	Ictaluridae
Clarias catfish	*Clarias* spp.	Clariidae
Pangasid catfish	*Pangasius* spp.	Pangasidae
Tilapia	*Tilapia* spp.	Cichlidae
Grey mullets	*Mugil* spp.	Mugilidae
Eels	*Anguilla* spp.	Anguillidae
Rainbow trout	*Salmo gairdneri*	Salmonidae

of Europe and the United States, and in many Latin American countries. The ubiquitous grey mullets found in tropical and semi-tropical waters around the world are also widely cultivated. Eels, which are high-valued species, are cultivated intensively in the Far East, and generally less intensively in Europe. Another highly valued species is the rainbow trout, the species most widely cultured commercially of the trouts.

In addition to listing the fishes mentioned in this paper, a number of definitions are required as preliminary to the economic analysis that follows:

(*a*) *Monoculture*—cultivation of a single species within a pond. (Animals high on the food chain and often supported by direct feeding, such as trout, are usually monocultured, but any species can be so cultivated.)

(*b*) *Polyculture*—the simultaneous rearing of a number of different species (or age-groups, in some instances) to make more efficient use of the entire pond environment. (The culture of the Chinese carps is a classic example of polyculture designed to fill most of the available feeding niches.)

(*c*) *Intensive culture*—one which uses improved techniques (including scientific pond design, fertilization, supplemental feeding, stock manipulation, and pest control) resulting in high production.

(*d*) *Extensive culture*—one which uses only traditional techniques (such as dependence upon the natural productivity of the water and little control over the stocks) usually resulting in low production.

The economic analysis that follows will make numerous comparisons between the methods outlined above.

2 Economic analysis by species, techniques and systems

2.1 *Milkfish*

Milkfish (*Chanos chanos*) is one of the most important pond-raised finfish in terms of land area used and in quantity of production. Its culture utilizes about 374 000 ha of land, employs about 200 000 people and produced over 160 000 tons of fish in 1973.

The milkfish is an algal feeder and a fast grower, so that it can be produced at relatively low cost to meet the animal protein requirement of people with low purchasing power. In addition, milkfish production can be managed with reliable profit on saline lands unsuitable for agriculture and animal husbandry. It is, therefore, one of the most appropriate measures for animal protein production in those developing countries in which such culture is possible.

The major producers of milkfish are Indonesia, the Philippines, and Taiwan Province of China. Their annual production ranges from 250 to over 3 000 kg/ha due to differences in culture techniques. Reliable cost-return data for commercial-scale milkfish farming under different techniques are difficult to obtain. The results of field surveys in the Philippines and Indonesia are summarized in Tables I–VII. These figures should be considered as indicative of relative trends in costs related to various culture techniques in the areas where surveys were conducted, rather than absolute quantitative figures, because the time spent and localities covered in the surveys were limited. It is evident from the data that costs and returns of milkfish farming vary according to culture techniques and management systems.

2.1.1 *The Philippines*

2.1.1.1 Intensive versus extensive culture. Two types of techniques are used in the Philippines for milkfish culture: intensive and extensive. Monoculture or polyculture may be practised for each of these techniques.

(*a*) *Monoculture.* In the intensive monoculture operation, fertilizer and feed, interest, and marketing are the major cost items, accounting for about 39, 19 and 15% respectively of the total operating cost. In the extensive monoculture operation, interest and land lease are the major cost items, accounting for about 47 and 24% respectively of the total operating cost.

TABLE I
COSTS OF AND RETURNS FROM MILKFISH CULTURE/HA IN THE PHILIPPINES (1975)
INTENSIVE—MONOCULTURE

Items	*Quantity*	*Value (P.Ps.)*	%
A. Construction costs		16 000	5·8
B. Operating costs			
Fry and fingerlings	6 500	592	
Fertilizer and feed			
—chemical (16–20–0) (kg)	1 500	3 000	
—chicken manure (kg)	2 000	560	
—rice bran (bags)	20	420	
		3 980	39·3
Pesticide		300	2·9
Labour		540	5·3
Lease		1 000	9·8
Marketing[a]		1 540	15·2
Maintenance and depreciation		225	2·2
Interest[b]		1 920	18·9
Taxes		17	
Total		10 114	
C. Production (kg/ha/year)	3 250	14 000	
D. Cost/kg		3·11	
E. Profit		3 886	
F. Rate of return on investment			24·2
G. Rate of return on operating costs			38·4

[a] Computed at 11% of total revenue
[b] Computed at 12% of construction cost/year
Source: Field interview in Iloilo City area (1975)

The annual stocking rate of intensive operation averages about 6 500 fry and fingerlings/ha compared with about 1 500/ha for extensive operations. The stocking rate varies mainly with the fertility of the ponds which can be improved by fertilization and supplementary feeding. The annual cost of fertilizer and feed of intensive operation averages about P.Ps. 4 000/ha, compared with about P.Ps 300 for the extensive one[1]. This is one of the major factors allowing the high stocking rate and hence high yield in the intensive operation. The annual yield averages about 3 000 kg/ha in the intensive operation, compared with about 500 kg/ha in the extensive operation. The total cost of production is higher with more fertilizer than with less, but since the level of production is also higher, the cost of production per unit of milkfish is relatively low. The cost of production per kg of milkfish is estimated as about P.Ps. 3·11 in the intensive operation, compared with about P.Ps. 8·17 in the extensive operation. It is profitable to use more fertilizer as long as the cost per unit of fertilizer does not exceed the value of the milkfish product.

The rate of return on investment in the intensive operation is about 24% per annum; it takes about five years to pay off the original investment. In the case of an extensive

[1] US$ 1·00 = Philippine pesos (P.Ps.) 7·50

TABLE II
COSTS OF AND RETURNS FROM MILKFISH CULTURE/HA IN THE PHILIPPINES (1975)
EXTENSIVE—MONOCULTURE

Items	*Quantity*	*Value (P.Ps.)*	%
A. Construction costs		16 000	
B. Operating costs			
Fry and fingerlings	1 500	210	5·1
Fertilizer and feed			
—chicken manure (kg)	1 000	230	
—urea		50	
		280	6·8
Pesticide		50	1·2
Labour		160	3·9
Lease		1 000	24·4
Marketing[a]		225	5·5
Maintenance and depreciation		225	5·5
Interest[b]		1 920	46·9
Taxes		17	
Total		4 087	
C. Production (kg/ha/year)	500	2 250	
D. Cost/kg		8·17	
E. Profit		1 837	
F. Rate of return on investment			11·5
G. Rate of return on operating costs			45·0

[a] Computed at 11% of total revenue
[b] Computed at 12% of construction cost per year
Source Field interview in Iloilo City area (1975)

TABLE III
COSTS OF AND RETURNS FROM MILKFISH CULTURE/HA IN THE PHILIPPINES (1975)
INTENSIVE—POLYCULTURE

Items	*Quantity*	*Value (P.Ps)*	%
A. Construction costs		16 000	
B. Operating costs			
Fry and fingerlings			
—milkfish	3 500	525	5·8
—shrimp	3 000	360	4·0
Fertilizer and feed			
—chicken manure		2 400	
—urea		135	
		2 535	28·0
Labour		400	4·4
Equipment and supplies		150	1·7
Pesticide		50	0·1
Lease		1 000	11·1
Marketing[a]		1 843	20·4
Maintenance and depreciation		225	2·5
Interest[b]		1 920	21·3
Taxes		17	
Total		9 025	
C. Production (kg/ha/year)			
Milkfish	2 500	11 250	
Shrimp	250	5 500	
Total	2 750	16 750	
D. Cost/kg		3·64	
E. Profit		7 725	
F. Rate of return on investment			48·0
G. Rate of return on operating costs			86·0

[a] Computed at 11% of total revenue
[b] Computed at 12% of construction cost per year
Source: Field interview in Iloilo City area (1975)

operation, there is a loss. However, most of the operators interviewed own their land and pay no interest on the initial investment. They are, therefore, on break-even level after the costs of lease and interest are excluded.

Intensive operation requires more labour than extensive

TABLE IV
COSTS OF AND RETURNS FROM MILKFISH CULTURE/HA IN THE PHILIPPINES (1975)
EXTENSIVE—POLYCULTURE

Items	*Quantity*	*Value (P.Ps.)*	%
A. Construction costs		16 000	
B. Operating costs			
Fry and fingerlings			
—milkfish	1 200	132	2·7
—shrimp	1 429	171	3·5
Feed		200	4·1
Labour		160	3·3
Equipment and bamboo		150	3·1
Lease		1 000	20·6
Marketing[a]		880	18·1
Maintenance and depreciation		225	4·6
Interest[b]		1 920	39·5
Taxes		17	
Total		4 855	
C. Production (kg/ha/year)			
Milkfish	800	3 600	
Shrimp	200	4 400	
Total	1 000	8 000	
D. Cost/kg		5·28	
E. Profit		3 145	
F. Rate of return on investment			20·0
G. Rate of return on operating costs			65·0

[a] Computed at 11% of total revenue
[b] Computed at 12% of construction cost per year
Source: Field interview in Iloilo City area (1975)

operation due to fertilization and more frequent stocking and harvesting. It is estimated that intensive operation requires about 0·23 full-time man-years of labour/ha, compared with about 0·08 in an extensive culture operation. The relative efficiency of labour in the two types of operation can be evaluated by comparing their annual production. A full-time farmer using intensive operation produces about 14 000 kg of milkfish, compared with about 6 300 kg derived by the extensive operator.

(*b*) *Polyculture.* In the Philippines, the giant tiger shrimp (*Penaeus monodon*) has been a popular species to stock with milkfish in a polyculture operation. Fertilizer, marketing and interest, the major cost items in the intensive polyculture operation, account for about 28, 20 and 21% respectively of the total operating cost. In extensive polyculture operation, interest and land lease are the most important cost items, accounting for about 40 and 21% respectively of the total operating cost. The total stocking rate of intensive operation averages about 6 500 fry and fingerlings/ha compared with about 1 630/ha for extensive operation. The first type of operation uses about 12 times more fertilizer and about 3·3 times more of labour than that of the second. Intensive operation produces about 2 750 kg/ha of milkfish and shrimps compared with about 1 000 kg/ha in the extensive operation. Again, the cost of production/kg of milkfish is lower in the intensive than in the extensive operation, which is about P.Ps. 3·64 and P.Ps 5·28/kg respectively.

The rate of returns on investment in the intensive operation is about 48%: it takes about two years to pay off the initial investment. In the extensive operation, the rate of return on investment is about 20%: it takes about six years to pay off the initial investment.

2.1.1.2 Monoculture versus polyculture.

(*a*) *Intensive monoculture versus intensive polyculture.*

Fertilizer and feed, interest, and marketing are the major cost items with respect to both intensive monoculture and intensive polyculture. However, the first type uses more fertilizer and feed than the second. Fertilizer and feed costs about P.Ps. 4 000/ha, accounting for about 39% of the total operating cost in intensive monoculture, compared with about P.Ps. 2 535/ha, accounting for about 28% of the total operating cost in intensive polyculture. The stocking rates are about the same in both cases. The total costs of production as well as the costs of production/kg of milkfish are also very close. However, the profit is much higher in the case of intensive polyculture (P.Ps. 7 725/ha) compared to that of intensive monoculture (P.Ps. 3 886/ha), mainly because of the high price of shrimp.

(*b*) *Extensive monoculture versus extensive polyculture.* Interest, marketing, and land lease are the major cost items in both cases. The stocking rate is higher in extensive polyculture than that in extensive monoculture. The total cost of production in the former is about 29% higher, but since the annual production is about 100% higher, the cost of production/kg of milkfish is much lower than that of extensive monoculture.

2.1.2 *Indonesia.* The results of the field survey summarized in Tables V–VII indicate that:

(*i*) the stocking rate is on the order of 4 000/ha, 6 000/ha, and 16 000/ha for extensive monoculture, intensive monoculture, and intensive polyculture respectively[1]. The annual production per ha is on the order of 300, 1 000, and 960 kg respectively. The high yield from intensive monoculture and polyculture is mainly due to the application of fertilizer, feed, and pesticides;

(*ii*) although the total cost of production is relatively higher for intensive monoculture and polyculture than for an extensive operation, the cost of production per kg of fish is lower. The cost of production per kg of fish is estimated at about Rp. 650 for extensive monoculture, Rp. 260 for intensive monoculture, and Rp. 369 for polyculture[2];

(*iii*) the rates of return on investment and on operating capital for polyculture (42 and 70% respectively) are higher than those of intensive monoculture (15 and 34% respectively) and extensive monoculture (negative)[3];

(*iv*) labour, interest, land lease, and fry are the major cost items of milkfish production; and

(*v*) polyculture requires more labour than monoculture, and intensive monoculture more labour than extensive monoculture.

The above analysis indicates that the application of improved or intensive techniques in Indonesia and the Philippines provides better results than traditional techniques alone, and polyculture is better than monoculture in terms of per unit cost of production and profit rate.

2.1.3 *Economics of scale of operations.* The size of a farm is another factor affecting the cost of production. A recent study in the Philippines (Carandang and Darrah, 1973) shows that the cost of production of milkfish is about P.Ps. 3·89, P.Ps 2·31 and P.Ps. 2·09/kg for small, medium and large size farms respectively.[1] The larger the size of a fishpond, the smaller the amount of labour required per ha of pond. However, the optimal farm size to minimize cost cannot be determined without more detailed study.

TABLE V
COSTS OF AND RETURNS FROM MILKFISH CULTURE/HA IN INDONESIA (1975)
EXTENSIVE—MONOCULTURE

Items	*Quantity*	*Value (Rp.)*	%
A. Construction costs		600 000	
B. Operating costs			
Fry	4 000	20 000	10·3
Fertilizer and feed		—	—
Pesticide		—	—
Labour		22 000	11·3
Maintenance and repair		5 000	2·6
Lease		50 000	25·6
Taxes		6 000	3·1
Marketing (paid by buyer)		—	—
Interest		72 000	36·9
Depreciation		20 000	10·3
Total		195 000	
C. Production (kg/ha/year)	300	120 000	
D. Profit		−75 000	
E. Cost/kg		650	
F. Rate of return on investment			—
G. Rate of return on operating costs			—

Source: Field interview in Central Java (1975)

TABLE VI
COSTS OF AND RETURNS FROM MILKFISH CULTURE/HA IN INDONESIA (1975)
INTENSIVE—MONOCULTURE

Items	*Quantity*	*Value (Rp.)*	%
A. Construction costs		600 000	
B. Operating costs			
Fry	6 000	30 000	11·5
Fertilizer and feed			
—urea (kg)	120	9 600	
—rice bran (kg)	400	6 000	
—others (kg)	500	7 500	8·9
Pesticide		16 000	6·1
Labour		24 000	9·2
Maintenance and repair		8 000	3·1
Lease		50 000	19·2
Marketing (paid by buyers)		—	—
Interest		72 000	27·6
Taxes		17 500	6·7
Depreciation		20 000	7·7
Total		260 600	
C. Production (kg/ha/year)	1 000	350 000	
D. Profit		89 400	
E. Cost/kg		260	
F. Rate of return on investment			15·0
G. Rate of return on operating costs			34·0

Source: Field interview in Central Java (1975)

2.1.4 *Inter-country comparison.* The annual yield per ha in Taiwan Province of China averages about 2 000 kg, compared with about 600 kg in the Philippines and about 350 kg in Indonesia. The high yield in Taiwan is mainly due to the relatively high stocking rate which averages about 10 000 fry and fingerlings per ha, compared with about 6 000 in the Philippines and about 2 000 in Indonesia. Fertilization, supplementary feeding, stock manipulation, and control of predators are the major factors which

[1] The stocking rate for polyculture consists of 6 000 milkfish and 10 000 shrimp/ha

[2] US$ 1·00 = Rp. 415

[3] Extensive monoculture (negative) denotes actual loss in terms of net income. However, it should be considered that the family may own the land, the operator may use his own family for labour, and many derive material benefits in terms of food fish for the family

[1] In this study the arbitrary classification used for farm sizes is: small, less than 10 ha; medium, 10–39 ha; and large, 40 ha and above

TABLE VII
COSTS OF AND RETURNS FROM MILKFISH CULTURE/HA IN INDONESIA (1975)
INTENSIVE – POLYCULTURE

Items	*Quantity*	*Value (Rp.)*	%
A. Construction costs		600 000	
B. Operating costs			
Fry			
—milkfish	6 000	30 000	8·5
—shrimp	10 000	50 000	14·1
Fertilizer (kg)	300	36 000	10·1
Pesticide			
—Brestan 60 (kg)	0·5	4 000	1·1
—Derris root (kg)	5	2 500	0·7
Labour		50 000	14·1
Maintenance and repair		10 000	2·8
Lease		50 000	14·1
Marketing (paid by buyers)		—	—
Interest		72 000	20·3
Taxes		30 200	8·5
Depreciation		20 000	5·6
Total		354 700	
C. Production (kg/ha)			
Milkfish	700	280 000	
Shrimp	260	324 000	
Total		604 000	
D. Profit		249 300	
E. Cost/kg		369	
F Rate of return on investment			42 0
G. Rate of return on operating costs			70 0

Source Field interview in Central Java (1975)

permit the high stocking rate and hence high yield in Taiwan Province (Shang, 1976).

It is estimated that about two thirds of the milkfish farms in the Philippines and the majority of those in Indonesia are extensive operations. Their productivity could be increased many times through adaptive modernization and intensification utilizing the Taiwan Province experience. Since the construction costs of fishponds are very high and since there are shortages of capital in these two countries, the first priority for milkfish pond development would, in the short-term programme, appear to be an increase in productivity of existing fishponds. This would serve to increase the farm operator's income as well as the supply of protein for the expanding population.

The milkfish industry in Indonesia, the Philippines, and Taiwan Province faces two major problems: high cost of fertilizer, and shortage of fish fry. Fish compete with other agricultural crops for fertilizer. The price of fertilizer in the Philippines has increased about 400% since 1970 and many fishpond operators continue using traditional techniques because of the high cost of fertilizer.

All milkfish fry are collected from coastal waters and their availability fluctuates widely in time and space. Shortage of fry in some years limits full-scale intensive operation and expansion of the industry. The ultimate solution to this problem appears to be the breeding of milkfish in captivity.

2.2 *Carps*

The total world production of carps is estimated at over two million tons. Several species of carps are cultured intensively. The common carp and Chinese carps have a long history of cultivation and their use is widespread, but the Indian major carps have not yet become as popular for culture outside their native area.

2.2.1 *Intensive versus extensive culture.* The merits of feeding as against not feeding carp culture are related primarily to the economics of the culture operations. Table VIII gives a sample comparison of costs and production of fed and unfed common carp in Israel. The total operating cost with feeding is about 57% higher than without, but since the yield is over 100% higher, the cost of production per ton of carp is about 40% lower.

Table IX shows the yield of common carp in various countries under different culture methods. Intensive culture with feeding or fertilization increases the production many times over that of extensive culture. Additional fertilization and supplementary feeding should be undertaken, however, only if the resulting increase will more than offset their costs.

2.2.2 *Polyculture.* The practice of polyculture with carps results in a significantly higher yield than that of monoculture.

In Chinese fishponds, a significant increase in production has long been obtained through polyculture. In Israel, polyculture using common carp and tilapia has increased total yields by 13–35% over that of monoculture. Polyculture without feeding of grass carp, silver carp, bighead and common carp in ponds formerly used for the monoculture of common carp, has resulted in production increases of 400–600 kg/ha in central USSR and 600–1 000 kg/ha in

TABLE VIII
COSTS PER HA AND PER TON FOR COMMON CARP CULTURE IN ISRAEL WITH AND WITHOUT FEEDING

	With feeding		*Without feeding*	
	Per ha (US$)	*Per ton (US$)*	*Per ha (US$)*	*Per ton (US$)*
Charges for capital invested in ponds and fishing gear	360	169	360	360
Water	210	99	210	210
Fertilizer	87	41	87	87
Maintenance	106	50	106	106
Feed	370	174	—	—
Labour	286	116	150	150
Marketing costs	32	15	12	12
Interest on working capital	5	2	2	2
General and overhead expenses	10	5	8	8
Total	1 466	671	935	935

Source: Tal and Hepher (1967)

TABLE IX
YIELDS FROM COMMON CARP CULTURE IN VARIOUS AREAS

Country	*Culture method*	*Yield (kg/ha/year)*
Europe	Natural growth in ponds	25–400
	Growth in ponds with feeding	100–400
	Intensive culture in ponds	1 500
India	Natural growth in ponds	400
	Growth in ponds with feeding	1 500
Japan	Growth in irrigation ponds	100–500
	Intensive culture in ponds	5 000
Yugoslavia	Culture in ponds without fertilizer	780
	Culture in ponds with manure	1 500–2 000

Source: Bardach, Ryther and McLarney (1972)

TABLE X
COSTS OF AND RETURNS FROM COMMON CARP CULTURE IN A 555 HA STATE FARM IN POLAND (1969)

Items	*Value ('000 Zl.[a])*	%
A. Capital investment		
Construction of ponds	18 659	—
Equipment	6 667	—
Total	25 326	—
B. Operating costs		
Stocking material	74	1·7
Feeds	1 722	39·4
Fertilizer	182	4·1
Other material	10	0·2
Labour	1 172	26·8
Pesticide	—	—
Maintenance and repairs	314	7·2
Other costs	418	9·6
Depreciation	465	10·6
Interest on loans	18	0·4
Total	4 375	100·0
C. Income	5 665	
D. Profit	1 290	
E. Rate of return on investment		5·0
F. Rate of return on operating costs		30·0

[a] US$ 1·00 = Zl 19·92
Source. Pillay (1973)

TABLE XI
COSTS OF AND RETURNS FROM INDIAN CARP CULTURE IN A 3·5 HA FRESHWATER POND IN WEST BENGAL, INDIA (1971)

Items	*Value (I.Rs.[a])*	%
A. Capital investment		
Value of land	40 000	—
Construction of ponds	49 000	—
Equipment (nets)	1 022	—
Total	90 022	—
B. Operating costs		
Stocking material	20 000	44·2
Feeds	144	0·3
Fertilizers	2 500	5·5
Labour	14 900	32·9
Pesticides	12	—
Maintenance and repairs	140	0·3
Other costs	7 626	16·8
(Handling and marketing of fish)	(476)	(1·0)
Total	45 322	100·0
C. Income	58 400	
D. Profit	13 078	
E. Rate of return on investment		15·0
F. Rate of return on operating costs		29·0

[a] US$ 1·00 = I.Rs. 8·20
Source: Pillay (1973)

TABLE XII
COSTS OF AND RETURNS FROM GREY MULLET AND CHINESE CARP POLYCULTURE IN A 1 HA FARM IN HONG KONG (1972)

Items	*Value (US$)*	%
A. Capital investment		
Value of land (rented land; see operating costs)	—	—
Construction of ponds	19 000	—
Equipment	4 011	—
Total	23 011	—
B. Operating costs		
Stocking material	1 123	7·6
Feeds	5 769	39·0
Fertilizers	538	3·6
Labour	1 938	13·1
Maintenance and repairs	1 923	13·0
Other costs	3 501	23·7
(Annual rent of land)	(3 000)	(20·3)
Total	14 792	100·0
C. Income	23 692	
D. Profit	8 900	
E. Rate of return on investment		39·0
F. Rate of return on operating costs		60·0

Source: Pillay (1973)

TABLE XIII
COSTS OF AND RETURNS FROM COMMON CARP AND CHINESE CARP CULTURE IN A 0·61-HA POND IN MALAYSIA (1970)

Items	*Value (M.$[a])*	%
A. Fixed capital	4 300	
B. Operating costs		
Fry	113	34·0
Fertilizer and feed	120	35·0
Labour	64	19·0
Depreciation	30	9·0
Others	6	2·0
Total	333	
C. Revenue	692	
D. Profit	359	
E. Return on fixed capital		8·3

[a] US$ 1·00 = M.$ 2·25
Source: IPFC (1970)

TABLE XIV
COSTS OF AND RETURNS FROM COMMON CARP CULTURE IN A 3 HA POND IN JAPAN (1970)

Items	*Value ('000 Yen[a])*	%
A. Fixed capital	450	
B. Operating costs		
Fry	506	20
Fertilizer and feed	1 302	51
Maintenance	—	—
Labour	415	19
Depreciation	30	1
Others	226	9
Total	2 539	
C. Revenue	3 894	
D. Profit	1 355	
E. Return on fixed capital		300
F. Return on operating costs		53

[a] US$ 1·00 = Yen 295
Source: IPFC (1970)

the south. With feeding and intensive pond fertilization, increases of 3 000–4 000 kg/ha have been achieved.

The cost-return data in Tables X–XIV show that profit rates of carp culture in Poland, India, Hong Kong, Malaysia and Japan are favourable under proper management. Feed and/or fertilizer, fry, and labour constitute the major

cost items. The cost of feed and fertilizer can be reduced through the following measures: (*i*) use of sewage-enriched water; (*ii*) use of feed formulae with local materials (*eg*, in China, use is made of grain bran, duckweed, fly pupa powder, silkworm pupa powder, and snail shell powder); and (*iii*) fish-cum-animal farming.

2.2.3 *Fish-cum-animal farming.* Joint culture of ducks, poultry and pigs in combination with aquaculture on a commercial scale reduces the cost of fertilizer and feed and increases the production of animal protein per unit area. In addition, the environmental pollution often resulting from warm-blooded animal husbandry can be avoided and the wastes utilized for an increase in the fish crop.

Experiments in the German Democratic Republic have shown that an average of 100 kg of extra carp meat can be obtained by keeping 300 ducks on a 1 ha fishpond. The average annual production of carps in a fish-cum-duck farm in Taiwan Province is about 3 500 kg/ha. The daily supply of duck droppings is sufficient to fertilize the pond to promote and maintain a rich growth of natural fish food organisms. At the same time, part of the droppings is eaten by fish directly. Therefore, application of fertilizer and/or supplemented fish feed is not necessary, thus greatly reducing the cost of production.

2.3 *Catfish*

Thailand, the United States, and a number of Latin American countries are the major catfish-producing countries. Cost-return on catfish farming is only available from the first two countries.

2.3.1 *Thailand.* Clariid catfish are a popular and highly desirable freshwater fish in Thailand. The demand for catfish is expected to expand as the urban population is growing rapidly and as *per capita* income is also increasing. However, the number of catfish ponds has increased so rapidly since 1967 that by 1969 the supply of catfish exceeded the demand. The price fell sharply and many pond operators were forced out of business. From 1970–73, however, the price of catfish recovered and increased at an average of about 22% per year. A detailed market potential study seems necessary to guide future production.

Feed, the most important cost item, accounts for about 75% of the total annual operating cost (Table XV). Trash fish, which has been the most important feed used, accounts for about 57% of the total operating cost. The price of trash fish has almost doubled from 1970 to 1975. There is some evidence that the supply of trash fish may decline in the future due to increasing exploitation as well as man-made habitat modification. In addition, the main competing use for trash fish, making fish meal, is causing an upward trend in trash fish prices since world prices for fish meal have been rising dramatically. If the price of trash fish rises faster than the price of catfish, and if there is no further improvement in culture technique to offset the increased cost of production from this source, the profit will be reduced. This could be a limiting factor to the expansion of the industry.

2.3.2 *USA.* Channel catfish farming is a growing industry in the United States. The major incentive for this growth has been the excellent return on investment achieved by some producers—sometimes as high as 55%.

The cost-return data in Table XVI shows that managerial skill is the major factor affecting the cost and profit. The cost of production is US$ 0·73/kg with average management, compared with only US$ 0·53/kg with superior management. With expansion of the industry and improvements in culture techniques, the American catfish could become a food staple.

TABLE XV
COST AND RETURNS OF CATFISH CULTURE IN THAILAND (1975)

	Farm A		*Farm B*		*Farm C*		*Farm D*		*Average* (%)
	Baht[a]	%	*Baht*	%	*Baht*	%	*Baht*	%	
1. Gross returns	263 865		255 816		41 140		130 200		
2. Stocking material	17 360	9·1	26 240	12·6	3 900	18·1	8 500	15·2	13·8
3. Feeds									
Trash fish	110 223	57·9	106 961	51·3	12 800	59·3	33 294	59·7	57·1
Rice bran	18 600	9·8	13 450	6·5	1 280	5·9	2 370	4·3	6·6
Broken rice	20 160	10·6	30 124	4·5	975	4·5	4 200	7·6	6·8
Manufactured feeds	760	0·1	4 330	2·1	700	3·2	558	1·0	1·6
Total feeds	149 743	78·6	154 864	74·4	15 755	73·0	40 422	72·5	74·6
4. Disease control	4 012	2·1	5 312	2·5	544	2·5	1 736	3·1	2·6
5. Operation and repair of equipment and ponds	4 495	2·4	7 860	3·8	1 425	6·6	426	0·8	3·4
6. Labour (actual and imputed)	8 180	4·3	6 587	3·2	1 740	8·1	3 187	5·7	5·3
7. Total direct costs	183 790	96·4	200 863	96·4	19 464	90·2	54 271	97·3	95·1
8. Depreciation (6 months)									
Equipment and building	3 720	2·0	4 149	2·0	1 675	7·8	1 058	1·9	3·4
Ponds (based on ten-year life)	[b]		2 500	1·2	150	0·7	325	0·6	0·8
9. Actual rent (6 months) or return to land at 5%/year	3 000[c]	1·6	812[d]	0·4	285[d]	1·3	98[d]	0·2	0·9
10. Total costs	190 510	100·0	208 324	100·0	21 574	100·0	55 752	100·0	
11. Net earnings (profit) (1–10)	73 355		47 492		19 566		74 448		

[a] US$ 1·00 = Baht 20
[b] Included in rent
[c] Actual rent
[d] Return on land in operator-owned site

Source: Kloke and Potaros (1975)

The US catfish industry is, however, facing strong competition from lower-priced imported catfish, especially from Brazil, the major exporting country to the United States.

2.4 *Tilapia*

Tilapia (there are many species) is a widely cultured pond fish both alone and in combination with other fishes. Inclusion of a predator is one form of polyculture, a practice which is becoming more popular in raising tilapia. In many cases, when tilapia is added to the existing pond culture community, total production rises without reducing production of the other fish species cultured. Tilapia is also often stocked in ponds to help control growth of weeds, which may interfere with fish culture.

Evaluation of tilapia culture in experimental farms in northeast Brazil indicated that the annual net profit/ha can reach B.Cr. 4 668 with an annual rate of return of 33% to the total cost of production before tax (Greenfield, Lira and Jensen, 1974)[1]. Feed and fertilizer, the most important cost items, account for about 46 and 17% respectively of the total operating cost (Table XVII). The annual production reaches 4 870 kg/ha. Experiments with tilapia culture in Alabama, Central African Empire, and Israel have also shown a production of 4 000–6 000 kg/ha.

Research into tilapia nutrition is greatly needed to determine which feeds are the best, cheap, and easily available and what feeding rates are most effective especially in countries where little money is available to purchase feeds.

2.5 *Mullet*

The grey mullet (*Mugil cephalus*) is predominantly a plant feeder and, therefore, a desirable species for pond culture. It is found in tropical and sub-tropical waters around the world. The biggest problem for the expansion of the industry is the uncertainty of the supply of naturally produced fry. As practised today, commercial mullet culture, is a low-intensity operation dependent on an unpredictable natural supply of fry. Mullets are often reared in polyculture with milkfish.

Experiments to breed grey mullets under controlled conditions have been conducted in many areas. Artificial spawning has been successful in Taiwan Province, Israel and Hawaii and there are indications that commercial production of fry may be possible shortly.

TABLE XVII
COSTS OF AND RETURNS FROM TILAPIA CULTURE IN NORTHEAST BRAZIL (1974)

Items	*Value (B.Cr.[a])*
A. Fixed cost	
Administrative surcharge	111
Pond and gear maintenance	350
Amortization, real estate	1 514
Amortization, equipment	112
Total	2 087
B. Variable cost	
Feed	6 417
Fertilizer	2 340
Water	632
Fingerlings	540
Interest on working capital	1 044
Operator's labour	312
Hired harvesting labour	42
Hired pond-bottom maintenance labour	35
Hauling and marketing expense	157
Miscellaneous and contingencies	240
Total	11 759
C. Total income (4 872 kg at B.Cr. 3·80/kg)	18 514
D. Profit	4 668

[a] US$ 1·00 = B.Cr. 6 4
Source: Greenfield, Lira and Jensen (1974)

Cost-return data of mullet culture in Hong Kong shows that labour and feed are the major cost items accounting for 25 and 22% respectively of the total operating cost (Table XVIII). Since the fixed cost is very high, the rate of return on fixed capital is only 4·5%.

2.6 *Eels*

Eels have been cultured commercially in Japan, Taiwan

[1] US$ 1·00 = B.Cr. 6·4

TABLE XVI
COSTS OF AND RETURNS FROM CHANNEL CATFISH CULTURE/HA IN THE UNITED STATES (1969)

Under average management	US$	*Under superior management*	US$
Growing expense		Growing expense	
Fingerlings (1 200 at US$ 0·4)	48	Fingerlings (1 200 at US$ 0·2)	24
Chemicals	25	Chemicals	30
Feed (180 days, 22·5 kg/ha, US$ 95/ton)	214	Feed (150 days, 33 kg/ha, US$ 85/ton)	191
Labour	40	Labour (self-feeders)	50
Water pumping	8	Water pumping	8
Fuel and miscellaneous supplies	4	Fuel and miscellaneous supplies	4
Harvesting (US$ 4·6/kg)	30	Harvesting (US$ 2·2/kg)	14
Maintenance and taxes	25	Maintenance and taxes	25
Depreciation	13	Depreciation (self-feeders)	15
Interest on working capital	14	Interest on working capital	12
Total	421	Total	373
Income (93% survival, 0·56 kg average weight, US$ 0·84/kg)	530	Income (93% survival, 0·68 kg average weight, US$ 0·84/kg)	636
Profit (before tax)	109	Profit (before tax)	263
Return on investment (before tax)	23%	Return on investment (before tax)	55%
Cost of production		Cost of production	
Not including interest on investment	0·66/kg	Not including interest on investment	0·48/kg
Including interest on investment	0·73/kg	Including interest on investment	0·53/kg
Including interest on investment and 20% tax on profit	0·75/kg	Including interest on investment and 20% tax on profit	0·73/kg

Source: US Department of the Interior, Bureau of Sport Fisheries and Wildlife

TABLE XVIII
COSTS OF AND RETURNS FROM GREY MULLET CULTURE IN A 8 HA POND IN HONG KONG

Items	*Value (US$)*	%
A. Fixed capital	48 000	
B. Operating costs		
Fry	9 650	14·0
Feed	15 000	22·0
Maintenance	5 000	7·0
Labour	16 800	25·0
Depreciation	10 000	16·0
Other	11 800	17·0
Total	68 250	
C. Revenue	90 000	
D. Profit	21 750	
E. Return on fixed capital		4·5
F. Return on operating costs		32·0

Source: Pillay (1973)

Province, and Korea, and attempts to initiate eel culture are under way in many other countries. Japan appears to be the most important eel-producing and consuming country in the world. However, the production of eel from both inland waters and culture ponds has declined because of water pollution, poor catches of eel seed (elvers), and diseases. The growing demand for eel in Japan has increased the area of eel farming in Taiwan Province from 148 ha in 1969 to about 1 200 ha in 1973. Many paddyfields have been converted into eel ponds. Over 90% of the eel production in Taiwan Province has been exported to Japan. At present, the eel industry in Taiwan Province earns about US$ 30 million and has a significant impact on the local economy. This is one of the good examples of how a cultured luxury fish can earn foreign exchange.

The cost of production of eel is available only from Taiwan Province (Table XIX). Here, eel ponds are constructed with bricks or concrete; therefore, the initial construction cost is as high as US$ 24 000/ha of pond. Seed eel and feed, the most important operating cost items, account for about 53 and 27% respectively of the total operating cost. The rate of return on initial investment is as high as 100% if the survival rate is over 70% and if the price of elvers does not exceed US$ 0·25 each. The supply and the price of elvers fluctuate annually and, in years of scarcity, the price can increase from US$ 0·03 to US$ 0·55 each. The shortage of elvers has been a limiting factor to the expansion of the eel industry not only in Taiwan Province but also in Japan.

TABLE XIX
COSTS OF AND RETURNS FROM A 4 HA EEL FARM IN TAIWAN PROVINCE OF CHINA (1972)

Items	*Value (US$)*	%
A. Construction cost	20 450	
B. Operating costs		
Seed eel	30 000	53·0
Feed	17 850	32·0
Wages	2 200	3·9
Maintenance and repair	2 350	4·1
Electricity	875	1·5
Chemicals	475	0·1
Rent	625	0·1
Depreciation	1 125	2·0
Miscellaneous	1 225	2·2
Total	56 725	
C. Production (14 000 kg)	70 000	
D. Profit	13 275	
E. Rate of return on investment		65·0
F. Rate of return on operating costs		23·0

Source: Shang (1973)

Eel farming is a very profitable business, but it is also a risky venture. The mortality can be as high as 100% if ponds are not properly managed.

2.7 *Rainbow trout*

Trout culture has a long history in the United States and some European countries due largely to the popularity of trout as a sport fish. The rainbow trout is among the major species used for commercial culture. Less difficult to feed and less demanding with regard to temperature and water quality than most other salmonids, they are to be found in coldwater fish farms throughout the world.

Cost-return data on rainbow trout culture is available to the authors at this time only from Ireland. Feed and labour are the major cost items; they account for about 52 and 17% respectively of the total operating cost (Table XX). The rate of return on investment is about 36%.

TABLE XX
COSTS OF AND RETURNS FROM RAINBOW TROUT CULTURE IN A 35 ACRE POND IN IRELAND (1970)

Items	*Value (£.Ir.[a])*	%
A. Capital investment		
Value of land	18 000	—
Construction of ponds	17 000	—
Total	35 000	—
B. Operating costs		
Stocking material	1 500	13·0
Feeds	6 000	51·9
Other materials	40	0·3
Labour	2 000	17·4
Maintenance and repairs	200	1·7
Other costs	1 000	8·7
(Transport to markets)	(1 000)	(8·7)
Depreciation	800	7·0
Total	11 540	100·0
C. Income	24 000	
D. Profit	12 460	
E. Rate of return on investment		36·0
F. Rate of return on operating costs		108·0

[a] US$ 1·00 – £.Ir. 0·45
Source: FAO/EIFAC files

Increased economic yield in the trout farming industry can be obtained through better application of existing feed manufacturing techniques and closer control on feeding.

3 Summary and conclusions

The economic viability of a given aquacultural practice is dependent upon the many technical, social and economic factors peculiar to a country or region. The blueprint for a profitable operation in one country is no guarantee of its successful application in another socio-economic setting. However, based upon the experience achieved in many countries on various species, it can be summarized in a general way that the profitability V of aquaculture production can be improved if: (*i*) the yield per unit land (or water) surface Q can be increased; (*ii*) the cost of production C can be reduced; and (*iii*) the price received P can be maintained in a high level as shown in the formula: $V = QP - C$. Many

disciplines, including biology, genetics, nutrition, ichthyopathology, engineering and economics contribute to the attainment of this profitability.

3.1 *Increase in yield*
The major factors used in estimating productivity per unit of fishponds Q are stocking rate N, survival rate R, and average weight of the individual fish at the time of harvesting W.

$$Q = (NR)W$$

Therefore, increase in stocking rate, survival rate and growth rate are the major elements to increase production.

3.1.1 *Increase in stocking rate*

(*a*) *Fertilization and supplementary feeding.* The stocking rates used and growth rates obtained are generally much higher with fertilization and supplementary feeding than without. The total costs of production are also higher with fertilization and feeding than without, but, since the level of production is also higher, the cost/ton of fish production may be lower, thus enabling the operators to benefit. Intensive milkfish farming is a good example of this.

(*b*) *Polyculture.* A significant increase in carp production is often obtained through polyculture in which the rearing of several species together makes more efficient use of the growing space and the total pond environment. Milkfish polyculture in Indonesia and the Philippines increases the profit of operations due to the stocking of high-value species together with milkfish.

(*c*) *Multiple-size stocking.* Chinese milkfish culturists have also increased the stocking rate by multiple-size stocking, *ie*, stocking the same species but in different size groups to make more efficient use of water space. The carrying capacity of a pond for different size groups is considerably greater than its capacity for any one size group alone.

3.1.2 *Increase in survival and growth rate*

(*a*) *Good pond management.* The survival and growth rates are dependent mainly on adequate pond management and the control of parasitism and diseases. Catfish farming in the United States furnishes good examples of the economic benefits of these practices.

(*b*) *Genetic improvement.* The survival and growth rate can also be increased by genetic improvements, such as selective breeding and hybridization.

3.2 *Reduction in cost of production and marketing*
The cost of production data collected in this study indicate that feed and fertilizer, fry, labour, marketing and interest are the major cost items.

3.2.1 *Reduction in cost of feed and fertilizer.* Fish culture competes with other agricultural activities for feed and fertilizer. The recent rapid increase in the price of feed and fertilizer has imposed a serious problem on the fish farming industry. As mentioned previously, the stocking rate can be increased through supplementary feeding and fertilization. It is also noted that additional fertilization will be profitable as long as the cost per unit of fertilizer does not exceed the value of the product. The high prices of fertilizer and feed may discourage fish operators from adopting these improved farming techniques and a search for suitable feeds and fertilizers at reasonable costs has high priority. Feeds prepared with locally available by-products are sometimes cheap. Philippine milkfish operators have also found that application of small amounts of fertilizer at more frequent intervals increases the efficiency of fertilization and reduces the cost. Sewage recycling for fish culture and the joint culture of ducks, poultry and pigs in combination with fish culture also reduces the cost of feed and fertilizer.

3.2.2 *Reduction in cost of fry.* Milkfish and to some extent catfish culture systems are dependent on the collection of fry from natural sources. The availability of fry fluctuates in time and space. In years of scarcity, the price of fry is high. A high price for fry means a high cost for fish, which either is transferred to consumers by charging a high price for fish, or reduces the producer's profit. The price of fry is expected to increase in the future due to increases in demand. The ultimate solution to the shortage of fry appears to be the breeding of these species in captivity. Meanwhile, short-range efforts should be made to increase the supply of fry by conducting surveys to locate new spawning grounds and by improvements in the efficiency of capture, distribution and fry survival.

3.2.3 *Reduction in labour and facility cost.* Milkfish farming in the Philippines demonstrates the economies of scale for different sizes of culture operations. The larger the farm size, the less the cost of labour and facility cost. Mechanization also reduces labour costs, but it may not be preferable in many developing countries where there is a good supply of available cheap labour and shortage of capital.

3.2.4 *Reduction in marketing cost.* As in agriculture, there is often a feeling that the producers of raw materials are not adequately rewarded for their labour, while wholesalers and brokers receive more than their share of the profit. For example, milkfish operators in the Philippines pay as much as 11% of the gross income for marketing cost (commission, transportation, ice, containers, *etc*). Co-operative marketing is likely to reduce the cost and is worth further study.

3.2.5. *Reduction in interest cost.* Fish culture, like other businesses, faces some risks. Initial construction costs are high and, in some cases, capital is less available for the production of relatively low-priced fish used for domestic consumption. Interest rate on loans for such purposes range from 12 to 30% per annum. Government-sponsored long-term and low-interest loans with simplified borrowing procedure would reduce the cost of production and stimulate expansion of the fish farming industry.

3.3 *Increasing the price received for farmed fish*
In a competitive market, the price level is mainly determined by supply and demand for fish in a particular market. However, price levels received by fish operators can be increased in the following ways:

3.3.1 *Improvement in quality.* High-quality fish commands a higher price. Most of the production from fishponds in Asian countries is sold in the fresh form. The quality of such fish can be improved through proper icing during transport and storage.

3.3.2 *Seasonality.* The price of fish usually fluctuates

seasonally. Phased stocking so that harvesting occurs at desirable times with respect to demand and price of fish can increase the average price received (Creencia, Valiente and Carandang, 1973).

3.3.3 *Co-operative marketing.* Individual fish operators are usually in a weak bargaining position and often receive very low prices. This situation may be improved through collective bargaining by fishpond operators' associations or co-operatives.

3.3.4 *Sale in different forms and markets.* Fish can be marketed fresh, frozen, cured, smoked, salted, canned, *etc.* The elasticity (price and income) of demand for different forms of fish are different. In addition, there are several types of market for fish: urban, rural, domestic, and foreign. The elasticity of demand for fish in these different types of market is also different. Allocation of fish to different market channels (Creencia, Valiente and Carandang, 1973) and selling it in different forms according to the elasticity of demand increases the average price and maximizes the revenue. This can also be done through organized co-operative marketing or fishermen's associations.

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Fish Production Costs Using Alternative Systems and the Economic Advantages of Double-Cropping

E. E. Brown

Abstract

In recent years, fish culturists have experienced rapidly rising production costs and slowly rising fish prices. As a result, interest has centred on producing fish by the most economical method

This paper compares the production costs of channel catfish (*Ictalurus punctatus*) and rainbow trout (*Salmo gairdneri*) in each of three different production systems: ponds, raceways and cages. It also shows how production costs can be lowered and, thus, how returns to management (net profit) can be increased by taking advantage of the different thermal requirements of the two species which allow both channel catfish and trout to be raised in the same production system during different times of the year. This technique of double cropping permits almost 100% utilization of a body of water during the year with each crop of fish contributing toward fixed costs. As a result, each crop of fish can be produced more cheaply than when only one crop is produced.

Net profits of producing channel catfish only were found to be highest for ponds and lowest for raceways. Net profits for cages were almost as high as the pond method.

For raising rainbow trout only, net profits were highest for raceways, followed by cages and ponds.

For the double-cropping technique net profits were increased as much as 320% Maximum profit was for ponds followed by cages and raceways.

Les coûts de la production de poisson selon divers systèmes et les avantages économiques d'une double récolte

Résumé

Ces dernieres années, les pisciculteurs ont dû faire face à une augmentation rapide des coûts de production alors que le prix du poisson n'augmentait que lentement. De ce fait, l'intérêt s'est porté sur la possibilité de produire du poisson par les méthodes les plus économiques.

Le présent document compare les coûts de production de l'ictalure tacheté (*Ictalurus punctatus*) et de la truite arc-en ciel (*Salmo gairdneri*) selon trois systèmes différents: en étangs, en raceways et en cages. Il indique également comment on peut faire baisser les coûts de production et, de ce fait, accroître les recettes de la gestion (bénéfice net) en tirant parti des besoins thermiques différents de deux espèces: l'ictalure tacheté et de la truite arc-en-ciel, dont l'élevage peut se faire dans le même système de production à différents moments de l'année. Cette technique de double récolte permet d'utiliser une nappe d'eau pratiquement à 100% pendant toute l'année, chaque stock cultivé prenant sa part des frais fixes. Il en résulte que l'on peut élever chaque espèce à plus bas prix que lorsque l'on n'en produit qu'une seule.

On a constaté que, lorsque l'on élevait uniquement l'ictalure tacheté, l'emploi des étangs donnait les plus gros bénefices nets, celui des raceways donnant les plus faibles. Les bénéfices nets réalisés par l'élevage en cage égalaient presque ceux obtenus par la méthode d'élevage en étangs.

Lorsque l'on élevait uniquement la truite arc-en-ciel, on réalisait les bénéfices nets les plus gros en utilisant les raceways, puis dans l'ordre les cages et les étangs.

La technique de la double récolte a permis d'accroître les bénéfices nets dans une proportion pouvant atteindre 320%. On a réalisé les bénéfices maximum dans l'ordre en étangs en cages, puis en raceways.

Costos de la producción piscícola con diversos sistemas y ventajas económicas del doble cultivo

Extracto

En los últimos años los piscicultores han tenido que afrontar un rápido aumento de los costos de producción sin que el aumento de los precios del pescado fuera igualmente rápido. En consecuencia, se busca la manera de producir pescado con el método mas economico posible.

En este documento se comparan los gastos de producción del bagre de canal (*Ictalurus punctatus*) y trucha arco iris (*Salmo gairdneri*) con tres sistemas distintos de producción: en estanques, en canales y en jaulas. Se indica además cómo pueden reducirse los costos de producción y, por tanto, aumentarse los beneficios netos approvechando las diversas necesidades térmicas de las dos especies, que hacen posible cultivar bagre de canal y truchas en un mismo sistema de producción en épocas distintas del año. Con esta técnica de doble cultivo es posible aprovechar casi al 100% una masa de agua a lo largo del año, dividiendo los gastos fijos entre los dos cultivos, lo que permite producir cada una de estas cosechas a precios más baratos que cuando se produce una sola cosecha.

En el caso del bagre del canal sólamente los beneficios netos resultaron máximos con el cultivo en estanques y mínimos con el cultivo en canales. En las jaulas se obtuvieron rendimientos netos casi tan elevados como en los estanques.

Por lo que se refiere al cultivo de trucha arco iris unicamente, los mejores rendimientos netos se obtuvieron con la cría en canales, seguida por la cría en jaulas y la cría en estanques.

Con la técnica del doble cultivo los beneficios netos aumentaron en un 320%. Los mayores beneficios se lograron con la cría en estanques, seguida por la cría en jaulas y en canales.

1 Introduction

In recent years, fish culturists have experienced rapidly

rising production costs and slowly rising fish prices. As a result, interest has centred on producing fish by the most economical method(s).

In the United States, the two major species of fish cultured are: channel catfish (*Ictalurus punctatus*), a warm-water fish; and rainbow trout (*Salmo gairdneri*), a cold-water fish. Three different production systems are used for culturing either species of fish. The most common method of producing channel catfish is open-pond culture, while raceways with continuous supplies of cold water are used for trout in many sections of the country. Limited quantities of each species are grown in cages. In recent years, in the southeast United States, where the climate is suitable, the practice of double-cropping fish has been introduced: catfish are grown during the seven months of April through October and trout from 15 November through March.

This paper compares the production costs of both species of fish for each of the three production methods when grown alone. In addition, it shows how production costs can be lowered by taking advantage of the difference in thermal requirements of the two species which allows both channel catfish and trout to be raised in the same production system during different times of the year. This technique permits almost complete utilization of a body of water throughout the year and each crop of fish contributes toward fixed costs. As a result, each crop of fish can be produced more cheaply than when only one crop utilizes the facility for only part of the year and bears all of the fixed costs.

This double-cropping method has been researched successfully for three years by the author and his co-workers at an experimental research station in South Georgia using raceways and cages in ponds. Double-cropping has been adopted by nearby fish culturists and is now being used in ponds and raceways.

The common denominator used in the paper is the number of fish stocked in each production system. The size of each of the three systems was such that 40 000 channel catfish and 60 000 trout could be grown to harvestable size in normal growing seasons. The examples used do not imply that these are the recommended sizes of production units for full-time employment. Labour requirements for any one of the three systems require two or three hours daily.

2 Single crop—channel catfish

Initial cost or investment cost for two 4·05 ha ponds was

TABLE I

BUDGETED COST AND RETURNS FOR TWO 4·05 HA PONDS PRODUCING EITHER CHANNEL CATFISH OR RAINBOW TROUT, USA (1975)[a]

	Channel catfish (*US$*)	*Rainbow trout* (*US$*)	
Initial costs			
Construction of ponds	25 000	25 000	
Land (8·1 ha of water area on 10·12 ha of land at US$ 1 112)	11 250	11 250	
Drain pipe	1 300	1 300	
Service building	600	600	
Boat	200	200	
Handling equipment	400	400	
Aerator	750	750	
Well	6 000	6 000	
Pump and motor	5 000	5 000	
Total initial costs	50 500	50 500	
Annual costs			
Fingerlings (40 000 at US$ 0·06 each for 12 cm fish)[d]	2 400	12 000	(60 000 at US$ 0·20 each for 15 cm fish)[e]
Feed (29·932[b] tons at US$ 165/ton)[d]	4 950	9 817	(23·13 tons at US$ 424·39/ton)[e]
Pumping cost (156·7 km³ at US$ 2·84/km³)[d]	445	315	(111 km³ at US$ 2·84/km³)[e]
Maintenance	50	50	
Labour—daily (2 h at US$ 1·85/h for 7 months)[d]	777	500	(4½ months)[e]
Harvesting (estimated at 6·6¢/kg)	1 140	1 200	
Fertilizer (909 kg of 20–20–5 at US$ 143/ton)	130	0	
Treatment costs	100	150	
Telephone	25	20	
Taxes (US$ 4·94/ha × 10·12 ha)	50	50	
Interest on investment (6%)	3 030	3 030	
Interest on working capital (8%)	279	550	
Depreciation[c]	1 604	1 604	
Total annual costs	14 980	29 286	
Cost of producing 1 kg of fish	0·867	1·61	
Feed conversion	1·7:1	1·5:1	
Returns to management			
17 234 kg of fish at US$ 1·102/kg[d]	18 992	32 006	(18 144 kg at US$ 1·764/kg)[e]
Less cost of production	14 980	29 286	
Net returns to management	4 012	2 720	

[a] Based on data from actual commercial operations
[b] Includes 318 kg of medicated feed
[c] Depreciation schedule of 40 years for pond and well; 25 years for service building; 10 years for drain pipe, boat, aerator, pump and motor; 5 years for handling equipment. Straight-line depreciation used
[d] These items pertain to channel catfish only
[e] These items pertain to rainbow trout only

US$ 50 500 (Table I). The largest cost item was for pond construction, followed by land cost. It was assumed that the ponds would be in an area having a high water table, such as is found in the Mississippi Delta area.

By comparison, the initial cost of two 10 segment raceway systems was US$ 27 700 (Table II). The most expensive item was the individual raceway segments. The two raceway systems of 10 segments each would be a closed system with water being recycled through the raceways from a spring-fed pond. Each segment would be 30·5 m long, 3 m wide at the bottom of the segment, with 2:1 side slopes and an average depth of 1·2 m. Each segment will produce the equivalent of 0·4 surface ha of pond production. Water is pumped from the storage pond to the initial segment of the raceway system. From there it flows by gravity through the raceway back to the pond. Approximately 1 850 m^3 of water is required per raceway segment.

An equivalent cage production system would require 80 1 m^3 cages and an initial (investment) cost of only US$ 6 100 (Table III). This method envisages using public or private waters where the rental cost of using these waters would be 10% of the harvestable crop of fish. This arrangement is being used in some southern states.

Assumed mortality for the 40 000 channel catfish fingerlings would be 5% in ponds and raceways and 10% in cages. With a 454 g average harvest weight/fish, 17 234 kg would be harvested from the pond system, 17 234 kg in the raceway system and 16 364 kg from the cage system (Tables I, II and III). Initial stocking weight would be 545 kg of fingerlings/system.

It should be noted that the price of feed fed to channel catfish in raceways and cages (Tables II and III) is of higher value per ton than feed fed to channel catfish in ponds (Table I). This is because in intensive stocking and rearing facilities the fish are unable to obtain the natural foods found in less intensive methods such as ponds (Simco). It should also be noted that a standard feed conversion of 1·7:1 was used for channel catfish in ponds, raceways and cages. Hill, Chesness and Brown (1974) using raceways had feed conversions for channel catfish as low as 1·3:1, and Hill (1975) and Schmittou (1970) had conversions of 1·3 to 1·7:1 in channel catfish cage research. However, the commonly used rate in commercial production systems is 1·7:1, a rate which Swingle (1967) has recommended as a realistic conversion rate for pond culture.

An opportunity cost of 6% was used for interest on investment of initial cost. Interest on working capital (borrowed money) was 8%. These costs were based on the average amount spent during the production cycle of all annual costs exclusive of interest on investment, depreciation and taxes (Tables I, II and III).

TABLE II

ACTUAL COST AND RETURNS FOR TWO 10-SEGMENT RACEWAY SYSTEMS PRODUCING EITHER CHANNEL CATFISH OR RAINBOW TROUT, USA (1975)[a]

	Channel catfish (US$)	*Rainbow trout* (US$)	
Initial costs			
Construction of pond (2·4 ha, 37 km^3)	7 500	7 500	
Land (pond and raceway segments, 4·86 ha at US$ 1 112)	5 400	5 400	
Construction cost[b] (US$ 700/segment × 20 segments)	14 000	14 000	
Service building	600	600	
Handling equipment	200	200	
Total initial costs	27 700	27 700	
Annual costs			
Fingerlings (40 000 at US$ 0·06 each for 12 cm fish)[e]	2 400	12 000	(60 000 at US$ 0·20 each for 15 cm fish)[f]
Feed (29·93[c] tons at US$ 209·48/ton)[e]	6 270	9 817	(23·13 tons at US$ 424·39/ton)[f]
Power cost for pumping (7 months at US$ 502)[e]	3 514	2 259	(4½ months at US$ 502)[f]
Maintenance	50	50	
Labour—daily (2 h daily at US$ 1·85/h for 7 months)[e]	777	500	(4¼ months)[f]
Labour—harvesting (2·25 ¢/kg)	380	400	
Treatment costs	100	100	
Telephone	35	20	
Taxes (US$ 4·94/ha × 4·86 ha)	24	24	
Interest on investment (6%)	1 662	1 662	
Interest on working capital (8%)	368	575	
Depreciation[d]	812	812	
Total annual costs	16 392	28 219	
Cost of producing 1 kg of fish	0·949	1·56	
Feed conversion	1·7:1	1·5:1	
Returns to management			
17 234 kg of fish at US$ 1·102/kg[e]	18 992	32 006	(18 144 kg at US$ 1·764/kg)[f]
Less cost of production	16 392	28 219	
Net returns to management	2 600	3 787	

[a] Based on actual data acquired at the experimental fish production facility in Tifton, Georgia
[b] Includes, pump, pipe, valves, head-walls, and earth moving
[c] Includes 318 kg of medicated feed
[d] Depreciation schedule of 40 years for pond; 25 years for construction cost of segments and service buildings; 5 years for handling equipment. Straight-line depreciation used
[e] These items pertain to channel catfish only
[f] These items pertain to rainbow trout only

The annual cost was lowest for the cage system (US$ 12 108). The annual cost for the pond system was US$ 14 980 and the annual cost for the raceway system was US$ 16 392.

The cost of producing channel catfish was lowest for cages, US$ 0·82/kg, and highest for the raceway system, US$ 0·95. The production cost/kg for ponds was US$ 0·87 (Tables I, II and III).

The return to management (or net profit) for producing one annual crop (210 days) was US$ 4 085 for cages, US$ 4 012 for ponds and US$ 2 600 for raceways (Tables I, II and III).

3 Single crop—rainbow trout

Initial costs (investment) are the same for each of the three cultural systems when raising trout instead of catfish (Tables I, II and III).

In raising only one crop of rainbow trout/year in the approximate grow-out period of 4½ months, each system was stocked with 60 000 15 cm fingerlings. The assumed mortality was 5%. The harvest weight of the 57 000 survivors was 18 144 kg for an average harvest weight of 318 g/fish. Stocking weight of 60 000 fingerlings in each system was 2 722 kg or 45·4 g each.

For rainbow trout production a standard feed conversion ratio of 1·5:1 was used. For pond culture this ratio was estimated by commercial producers. Hill, Chesness and Brown (1973) had average feed conversions of 1·3:1 in pilot raceway and cage production facilities. The range over several years was from 1·1:1 to 1·5:1. It was therefore considered that a rate of 1·5:1 for commercial facilities would be practical and attainable.

The annual costs including interest on investment, interest on working capital and total yearly depreciation for each of the three systems are shown in Tables I, II and III. The average cost of production/kg of fish sold was lowest in the cage system, US$ 1·53, followed by the raceway system, US$ 1·56. The pond system had the highest production cost/kg, US$ 1·61.

Returns to management (net profit) were US$ 3 755 for the cage system, US$ 3 787 for the raceway system and US$ 2 720 for the pond system.

4 Results of using a double-cropping system

The economic advantages of double cropping are that fixed costs are allocated over two crops of fish and more total weight of annual production is realized. For the illustration used in this paper, these fixed costs (interest on investment, depreciation and taxes) were US$ 4 684 for the pond system, US$ 2 498 for the raceway system and US$ 1 200 for the cage system. These joint costs were used only once in a double-cropping system and returns to management

TABLE III

ACTUAL COST AND RETURNS FOR AN 80 CAGE (1 M³ EACH) SYSTEM PRODUCING EITHER CHANNEL CATFISH OR RAINBOW TROUT, USA (1975)[a]

	Channel catfish (*US$*)	*Rainbow trout* (*US$*)	
Initial costs			
Cages (80 at US$ 50 each)	4 000	4 000	
Service building	600	600	
4 000 m² land at US$ 450	450	450	
Boat and motor	1 000	1 000	
Handling equipment	50	50	
Total initial costs	6 100	6 100	
Annual costs			
Fingerlings (40 000 at US$ 0·06 each for 12 cm fish)[d]	2 400	12 000	(60 000 at US$ 0·20 each for 15 cm fish)[e]
Feed (29·93[b] tons at US$ 209·48/ton)[d]	6 270	9 817	(23·13 tons at US$ 424·29/ton)[e]
Gasoline and oil (7 months)[d]	35	25	(4½ months)[e]
Labour—daily (3 h at US$ 1·85/h for 7 months)[d]	1 166	749	(4½ months)[e]
Labour—harvesting (2·25 ¢/kg)	360	400	
Chemicals	50	35	
Labour for treatment (80 h at US$ 1·85/h)[d]	148	111	(60 h at US$ 1·85/h)[e]
Telephone	35	20	
Maintenance	50	50	
Interest on investment (6%)	366	366	
Interest on working capital (8%)	294	542	
Depreciation[c]	934	934	
Total annual costs	12 108	25 049	
Cost of producing 1 kg of fish after paying 10% rent	0·824	1·53	
Feed conversion	1·7:1	1·5:1	
Returns to management			
(10% of 16 364 kg of fish produced, paid as water rent)[d]			(10% of 18 149 kg of fish produced, paid as water rent)[e]
14 694 kg of fish sold at US$ 1·102/kg[d]	16 193	28 804	(16 329 kg sold at US$ 1·764/kg)[e]
Less cost of production	12 108	25 049	
Net returns to management	4 085	3 755	

[a] Based on actual data acquired at the experimental fish production facility at Tifton, Georgia. The 1 m³ sized cages are commonly used in the USA rather than larger cages
[b] Includes 318 kg of medicated feed
[c] Depreciation schedule of 25 years on service building; 10 years for boat and motor; and 5 years for cages and handling equipment. Straight-line depreciation used
[d] These items pertain to channel catfish only
[e] These items pertain to rainbow trout only

were US$ 11 416 for the pond system, US$ 9 040 for the cage system, and US$ 8 885 for the raceway system (Table IV).

TABLE IV
COMPARISON OF RETURNS TO MANAGEMENT FOR SINGLE-CROPPING OR DOUBLE-CROPPING USING DIFFERENT CULTURAL METHODS, USA (1975)

(in US$)

Item	Returns to management (net profit)		
	Ponds	Raceways	Cages
Channel catfish only	4 012	2 600	4 085
Rainbow trout only	2 720	3 787	3 755
Double-cropping system (catfish followed by trout)	11 416	8 885	9 040

As indicated in Table IV, a double-cropping system could increase returns to management (net profit) as much as 320% over the single-cropping system. Year-round utilization of facilities is a sound management tool and, where conditions are favourable, this practice should be expanded.

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A Proposal for Economic Investigations of Fish Farms with Special Reference to Book-Keeping and Financial Analysis

L. Berge

Abstract

Economic investigations of fish farm operations are necessary to assess the efficiency of operations and provide bases for entrepreneurial decisions. It is suggested that such investigations should be carried out in three stages, viz., (*i*) an overall survey of the industry; (*ii*) detailed study of sample fish farms; and (*iii*) study of pilot farms. If a common book-keeping system is followed by fish farming industry, comparison of data will be possible. The contribution method of book-keeping seems to be simpler and better suited to fish farming. Based on this, some key indicators should be worked out for rentability, liquidity, solvency, *etc.*

A detailed chart of accounts for use in fish farm book-keeping is presented. Calculating production, budgeting of operations, income and cost, assets, liabilities and equity, are illustrated with examples. The key values to be calculated are degree of contribution, break-even point and security margin. An outline of financial analysis is described and an economic model of a fish farm presented along with illustrative examples. The 'internal rate of interest' and 'present value' are the two most precise methods for evaluating investment projects.

Propositions relatives à des enquêtes économiques sur les stations piscicoles (comptabilite, analyse financière, *etc.*)

Résumé

Les enquêtes économiques sur le fonctionnement des stations piscicoles s'imposent pour évaluer la rentabilité des opérations et servir de base aux décisions au niveau de l'entreprise. Il est suggéré que ces enquêtes soient réalisées en trois étapes: (*i*) étude d'ensemble de l'industrie; (*ii*) examen détaillé d'échantillons de stations piscicoles; et (*iii*) étude de stations pilotes. Si les industries piscicoles adoptent un système comptable unique, la comparaison des données en sera grandement facilité. La méthode comptable de la marge brute semble être la plus simple et la mieux adaptée à la pisciculture. Dans le cadre de ce système, il faudrait déterminer des indicateurs-clés pour la rentabilité, les liquidités, la solvabilité, *etc.*

L'auteur présente un modèle comptable détaillé convenant à la pisciculture. Il illustre par des exemples divers calculs: production, budget des opérations, recettes et dépenses, actif, passif et capital social. Les valeurs-clés dont le calcul s'impose sont le taux de marge brute, le seuil de rentabilité et la marge de sécurité. L'auteur indique les principes de l'analyse financière et décrit un modèle économique de station piscicole, étayé d'exemples. Le 'taux de rentabilité interne' et la 'valeur réelle' constituent les deux méthodes les plus précises pour l'évaluation des projets d'investissement.

Propuestas para el estudio económico de explotaciones piscícolas: teneduría de libros y análisis financiero

Extracto

Es necesario realizar estudios económicos de las actividades de las granjas piscícolas para evaluar la eficiencia de las operaciones y disponer de una base para las decisiones empresariales. Se sugiere que dichos estudios se realicen a tres niveles: (*i*) estudio general de la industria; (*ii*) estudio detallado de algunas granjas piscícolas tomadas como muestra; y (*iii*) estudio de granjas piloto. Si en la industria piscícola se utiliza un sistema común de teneduría de libros, la comparación de los datos resultará mucho más fácil. El método de contabilidad más sencillo y adecuado para la piscicultura parece ser el de contribución. Sobre la base de éste han de prepararse algunos indicadores de rentabilidad, liquidez, solvencia, *etc.*

Se presenta un cuadro detallado de diversos tipos de cuentas para uso en la teneduría de libros en piscicultura. Se ilustran con ejemplos el cálculo de producción, la presupuestación de actividades, los ingresos y costos, el activo, el pasivo y el activo social neto. Los valores clave que han de calcularse son el grado de contribución, el umbral de rentabilidad y el margen de seguridad. Se presenta un esbozo de análisis financiero y un modelo económico de una granja piscícola, con ejemplos ilustrativos. Los dos métodos más exactos para evaluar proyectos de inversión son la 'tasa interna de interés' y 'el valor actualizado'.

1 Introduction

The collection and analysis of data on costs and earnings in fish culture operations may serve several purposes: (*i*) it may help the managers of farms in systematically and realistically studying their own operations; (*ii*) it may facilitate comparisons between farms, and form the basis for entrepreneurial decisions on matters such as improvements in the efficiency of the enterprise; (*iii*) it may form the basis for policy decisions relating to fish farming, and facilitate co-operative action with regard to marketing, supply of feed, and stocking material, *etc.*

Yang (1965) lists the following aims for such studies: (*i*) determination of the relative profitability of various farm enterprises; (*ii*) assessment of causes or reasons for variations in the unit costs of production; (*iii*) establishment of efficiency and management standards; (*iv*) description of the most efficient practices and techniques of farm operations; and (*v*) determination of the optimum input requirements of each farm enterprise.

Few detailed studies on cost and earnings in fish farming have been made. It is, therefore, of importance to clarify the purposes and methods of such studies and the definition of concepts.

Yang (1965) points out that cost accounting begins where book-keeping and financial accounting ends, and that records and books properly designed and kept should

provide all the basic information required for cost determination. Taking into account these points, a system of fish farm investigations is proposed in this paper. In addition, a system of book-keeping, cost accounting and financial analysis is described.

2 Fish farm investigations

It is suggested that fish farm investigations should be carried out in three successive steps as follows:

2.1 *Overall survey of the fish farm industry*

The first step is to get a total overall survey of the fish farm industry. The main data collected could be: (*i*) number of enterprises; (*ii*) location of enterprises; (*iii*) type of production; (*iv*) total quantity produced and sales; (*v*) employment; (*vi*) investment.

This type of investigation does not require an expert on fish farming as it is not a detailed analysis of the farms. National bureaux of statistics with their systems for data collection and statistical analyses can easily carry it out. This general investigation may assist in selecting enterprises for further, more detailed investigations.

2.2 *Detailed study of sample fish farms*

A detailed study of sample fish farms is the next step. It should be based on a detailed questionnaire filled in by a person with a good knowledge of fish farming. This investigation could yield: (*i*) income and detailed cost analysis; (*ii*) key values for rentability, production, investment, *etc*; (*iii*) analysis of sales and markets; (*iv*) analysis of biological and technological relationships such as fish densities, feeding coefficients, growth rates, fencing and construction material, types of machinery used, *etc*.

2.3 *Establishment of pilot fish farms*

Pilot fish farms should be established to furnish data which require relatively detailed book-keeping and recording of relevant data. The operation of the fish farm should be planned in cooperation with the fish farmer and the investigator(s). During the pilot period the investigator should be in close touch with the fish farmer in order to assist him and control the operation and the data recording. In addition to factors mentioned under sections 2.1 and 2.2 above, examples of topics to be investigated are: (*i*) work efficiency and effect of mechanization to establish management standards or norms; (*ii*) production functions under practical fish farm conditions; (*iii*) production combinations and new production techniques.

3 Book-keeping and financial analysis

The book-keeping should serve two main purposes: (*i*) provide the fish farmer with data for controlling and analysing his operation; and (*ii*) provide information and statistics on aquaculture business.

A common book-keeping system for the fish farming industry will greatly increase the comparability and reliability of the data to the benefit of both the fish farmers and fish farm investigators.

3.1 *Book-keeping system*

It is important in any enterprise to have a system for collection and analysis of economic data. Budgets, forecasts and accounts of actual achievements must lend themselves to comparison. Therefore, estimates, budgets and accounts must be made on the same pattern; only then can they be used for planning and analysis.

The contribution method is an attempt to simplify economic calculations. Traditional accounting systems like the self-cost method are often characterized by some complexity, thus making it difficult for the manager to interpret the derived data. Linear programming is a relatively accurate method for solving specific economic problems, but this method requires more knowledge of mathematics. The planning of book-keeping for an aquaculture business by an accounting firm may be mainly divided into two types, *viz.*: (*i*) short-range planning; and (*ii*) long-range planning.

Traditional accounting systems are unsuited for short-range planning as costs which are fixed over a relatively long period of time are included in the production costs used for short-range decisions. The contribution method distinguishes fixed costs from direct variable costs and maintains this separation throughout the whole of the accounting system in reports and analysis. The common terms used in book-keeping are the following:

(*i*) Operating income: The value produced, *ie*, sales adjusted for changes in stock.

(*ii*) Variable costs: Costs which vary in step with production volume, *eg*, feeding material and wrapping. In a firm with several employees, wages may be both variable and fixed costs.

(*iii*) Contribution: Operating income minus variable costs, and indicates what remains for fixed costs and net profit.

(*iv*) Fixed costs: Do not vary at all with the volume of production. Examples are amortization, maintenance and interest.

(*v*) Net Profit: Total 'contribution' minus fixed costs. In a one-man enterprise this indicates what remains for remuneration for the owner's labour input.

From these concepts three key values can be calculated:

(*i*) Degree of contribution: The contribution in percentage of income.

(*ii*) Break-even point: The amount of income where the contribution is sufficiently large to cover the fixed costs. This point indicates the balance between profit and loss. At this point there will be no profit and no loss.

(*iii*) Security margin: The security margin gives the percentage that sales or income can decrease before the enterprise runs at a loss.

These key values are calculated in the following manner:

$$\text{(i) Degree of contribution: } \frac{\text{Contribution} \times 100}{\text{Income}}$$

$$\text{(ii) Break-even point: } \frac{\text{Fixed cost} \times 100}{\text{Degree of contribution}}$$

$$\text{(iii) Security margin: } \frac{(\text{Income} - \text{break-even point}) \times 100}{\text{Income}}$$

A profitability analysis carried out to compare various enterprises can only be realistic if their accounting systems are uniform. It is suggested that the contribution principle should form the basis of the accounting system and that

some key indicators be worked out for rentability, liquidity, solvency, *etc.*

The primary information to be collected for obtaining an overview of the economics of an aquaculture farm are listed below:

(*i*) *Income—cost*
- Operating income
 - Increased (+) or decreased (−) stock of finished goods
 - Cash and credit sales of goods and services
- Variable production cost
 - Variable labour cost
 - Variable production cost (corrected for decreased (+) or increased (−) stock of raw material)
- Contribution
- Fixed cost
 - Salaries
 - Indirect cost
 - Interest on loans
 - Depreciation on fixed assets
 - Net profit

(*ii*) *Assets—liabilities*
- Total assets
 - Fixed assets
 - Stocks
 - Current assets
- Total liabilities and equity
 - Long-term liabilities
 - Short-term liabilities
 - Equity

(*iii*) *Production, employees, capacity*
- Quantities produced
 - Volume of water in m^3, surface of ponds in m^2
- Man-hours per year
- Maximum production capacity

(*iv*) *Key values*
- Return on investment
- Ability to pay wages per man-hour yearly
- Investment per man-hour yearly
- Investment per kg produced
- Production in kg per man-hour yearly
- Production in kg per volume of water in m^3
- Utilization of capacity

(*v*) *Other key values*
- Rentability
- Liquidity
- Solvency

3.2 *Chart of accounts*

For proper financial book-keeping and cost accounting, a company needs a chart of accounts. A chart of accounts will fulfil the needs of recording data required by the company itself, satisfy laws and regulations relating to the maintenance of company accounts and enable the provision of statistics and information to appropriate authorities. The suggested chart of accounts is based on ten classes which are arranged as follows:

Financial accounting	Class 0	Assets, liabilities, equity
	Class 1	Expenses
Cost accounting	Class 2 to Class 7	May be employed according to the internal need of the company
Financial accounting	Class 8	Income
	Class 9	Results

In accordance with the above, a detailed chart of accounts has been worked out. This chart has been adapted to the special need of fish farming and to the contribution method of calculating (see Annex I, Chart of Accounts).

3.3 *Calculation of production*

The basis for a budget or a plan is the calculation of the cost and income expected. Examples of this may be the calculation for 100 kg of fingerlings or 100 kg of consumption fish. It is important to calculate in the same manner the result of a production operation. An example of a calculation sheet is shown in Annex II (Contribution Calculation).

3.4 *Budgeting of operations*

When calculations of the various products have been made, the extent of the products has to be decided. In this connexion, the most important factors to be evaluated are: water resources, production equipment, market conditions, available labour, *etc* (see Annex III, Rentability Budget).

3.5 *Survey of operations*

The next step is to prepare the survey of operation (see Annex IV) which is divided into four parts:

(*i*) Income and cost: This is a summary of the profit and loss account containing both the results of last year's operation and the budget for the current year.

(*ii*) Assets—liabilities—equity: This is the summary of the balance at the beginning and the end of the period. In addition, the two last columns show a cash-flow analysis, *eg*, one can see that the stocks have increased by, say N.Kr. 385 000, and short-term liabilities have decreased by N.Kr. 170 000.

(*iii*) Production, employees and capacity: This comprises technical data needed for calculating the key values.

(*iv*) For a more detailed explanation of key values see Annex V, Definition of Key Values.

4 Evaluation of investment projects

In section 3 an overview of book-keeping and financial analysis is given, along with an economic model of a fish farm, illustrated with an example (Annexes I–V). This model describes the situation in a given period of time and does not take into account cost and income that may occur at other periods of time.

In practical business one has to consider future investment possibilities which influence cost, income and the rentability of the enterprise.

Some possible criteria are therefore presented for evaluating the rentability of projects. Fig. 1 delineates the 'return on investment' in an aquaculture operation. It shows that the profit and interest on debts are related to total investment giving 14·5%. This example can be extended by introducing several periods of time and taxes on profit. The project considered requires an initial investment of N.Kr. 320 which can be totally depreciated over 6·4 years at an annual depreciation of N.Kr.50. The prognosis assumes a yearly revenue of N.Kr 2 500 and yearly operating cost of N.Kr 2 240. Income taxes are assumed to be 53% of

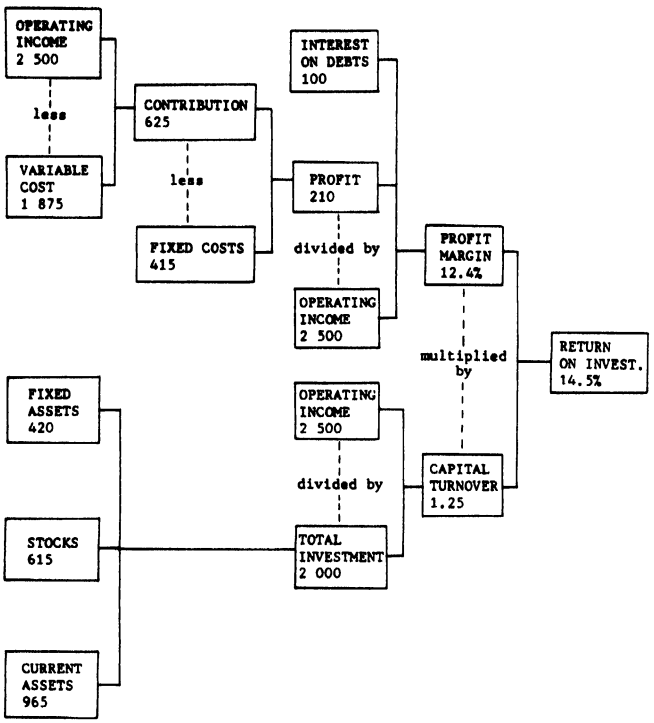


Fig 1. Return on investment

taxable income. For any year of operation the accounts will be:

	N.Kr.
Income	2 500
—operating costs ex. depreciation	−2 240
—depreciation	−50
Taxable income	210
Taxes 53%	−111
Return on investment after taxes	99

As a measure for rentability:

(*i*) Yearly profit before taxes: N.Kr. 210
Yearly profit after taxes: N.Kr. 99

(*ii*) Yearly cash flow:
Depreciation and return on investment before taxes: N.Kr. 260
Depreciation and return on investment after taxes: N.Kr. 149
These criteria only take into account the income of one year and disregard the capital invested. These criteria can, therefore, not be recommended.

(*iii*) Yearly return on initial investment:
Before taxes: 360:320 = 71·1%
After taxes: 99:320 = 30·9%
This criterion is better as it takes into account the initial investment. However, how long the capital is tied up in the project is not considered.

(*iv*) Yearly return on average investment:
Before taxes: 260:160 = 162·5%
After taxes: 99:160 = 61·9%
(With linear depreciation the average investment is 320:2 = 160).
This criterion takes into account depreciation of investment but the duration of the project is not considered.

(*v*) Pay-back time: Equals initial investment divided by yearly cash flow
Before taxes: 320:260 = 0·6 year
After taxes: 320:149 = 1·8 year.
This criterion comprises part of the time of the project and a part of the total investment and it is thought to be better than alternatives (*i*) to (*iv*). All criteria are easy to calculate but are associated with some obvious disadvantages. To an increasing degree the next two rentability criteria have been adopted for project evaluation.

(*vi*) Present value of the project: The present value of a project is the sum of all annual cash flow discounted to the present, less the sum of all investment discounted to the present.
This criterion takes into account the whole time of the project, the size of investment, depreciations, and cash flow. The choice of rate of discount may be difficult.

(*vii*) Internal rate of discount of the project: The internal rate of discount is the rate which makes the present value of the project equal to zero.
This criterion does not indicate anything concerning the amounts invested or recovered during the period of the project.
The last two criteria mentioned should both be used as they are closely related and supplement each other. But, in order to employ these correctly, one has to be familiar with the discounting technique and the concept of present value. It is not proposed to describe the detailed method of calculation but the calculation of present value and internal rate of discount in the case mentioned is shown below. Using the same example:

	N.Kr.
Yearly income	2 500
Yearly cost	2 240
Yearly depreciation	50
Taxes 53% of profit	
Loans of total capital	$\frac{1\,170}{1\,610} = 0{\cdot}73$
Equity of total capital	$\frac{440}{1\,610} = 0{\cdot}27$
Average rate of interest on loans	$\frac{100}{(1\,170 + 1\,300) \div 2} = 8{\cdot}7$

On equity 5% per annum interest is demanded. Discount will be:

$$0{\cdot}087 \times 0{\cdot}73\ (1-0{\cdot}53) + 0{\cdot}05 \times 0{\cdot}27 = 4{\cdot}3\%$$

Discounting factor of annuities:

$$\frac{1{\cdot}043^{6{\cdot}4} - 1}{0{\cdot}043 \times 1{\cdot}043^{6{\cdot}4}} = \frac{1{\cdot}335 - 1}{0{\cdot}043 \times 1{\cdot}335} = 5{\cdot}8$$

Present value of the project (P)

$$P = 5{\cdot}8\ [(1-0{\cdot}53)\ 2\,500 - (1-0{\cdot}53)\ 2\,240 + 0{\cdot}53 \times 50] - 320$$

$$P = 5{\cdot}8\ [(1\,175 - 1\,053 + 27) - 320]$$

$$P = 864 - 320 = 544$$

N.Kr. 1·00 invested in this project will, according to the prognosis, recover 544/320 = 1·70 in present value after having paid the initial investment, cost and taxes.

Internal rate of interest is the discount which makes

present value = 0. By trial, the internal rate of interest is found to be:

$$320\ (1+i)^{6\cdot4} = 544$$

$$(1/i)^{6\cdot4} = 1\cdot70$$

$$i = 8\cdot5\%$$

As has been mentioned, internal rate of interest and present value are the two most precise methods for evaluating investment projects. But they both require calculation of interest and annuities; this work can be simplified by the use of interest tables.

Annex I

Chart of Accounts

ASSETS

Current Assets
- Cash in hand and deposit with postal giro
- Bank deposit, term, on demand
- Claims on customers (including bills of exchange) and advances to suppliers
- Other claims
- Capitalized expenditure

Stocks
- Fish in stock and other finished goods
- Fish in production
- Feeds and other raw materials

Fixed Tangible Assets/Costs

Water and land properties and building sites
Ponds
Buildings
Machines, tools and transport equipment
Other fixed assets

Other Assets
- Patent and similar rights
- Mortgages and other bonds
- Shares
- Dwellings

TOTAL ASSETS

LIABILITIES

Short-term Liabilities
- Trade debts (including acceptances) and advances from customers
- Accrued salaries and holiday money, employee taxes deducted, unpaid
- Accrued interest payable
- Other short-term liabilities

Long-term Liabilities
- Current drawing accounts and building loans
- Mortgages, bonds
- Other long-term debts

Equity
- Share capital
- Funds
- Net profit/deficit

Depreciation Accumulated

TOTAL LIABILITIES AND EQUITY

PROFIT AND LOSS ACCOUNT

Operating Income
- Sales in cash and on credit
- Rent in kind, wages in kind, prerequisites for household
- Adjustment for inventory changes: fish in production
- Adjustment for inventory changes: fish in stock
- Subsidies and governmental support

Variable Cost

Variable Production Cost
- Purchase of fingerlings and stocking fish
- Purchase of feeds
- Purchase of medicines, fertilizers, *etc*
- Purchase of packing material
- Purchase of freight and transportation cost
- Insurance of fish in production and in stock
- Adjustment for inventory changes of feeds and other main production materials

Variable Labour Cost
- Cash wage and wages in kind (including social expenses)
- Board and lodging furnished by household

Contribution

Fixed Cost

Indirect Operational Cost
- Fuel
- Electricity
- Pond preparation and maintenance
- Running, maintenance, service of tools and equipment
- Rental for farm and water fees

Administrative Cost
- Contingencies, membership dues, subscriptions
- Commissions, patent and licence fees
- Advertisement and other selling expenses
- Insurance premiums
- Telephone, postage and office accessories
- Travelling expenses
- Auditing, juridical, technical assistance

Salaries
- Salaries and wages to administrative personnel
- Pensions
- Owner's calculated salary

Interest on Debts and Other Financial Expenses

Depreciation on Fixed Tangible Assets

Operational Profit

Other Income

Taxes

Net Profit

Annex II

Contribution Calculation
Product—Rainbow trout, 3 years, 2·5 kg/fish
Unit—100 kg live weight
Income

Production	*Saleable production*	*N.Kr.*	
		Prices	*Income*
Rainbow trout			
Grade I	80	15	1 200
Grade II	20	11	220
Total	100		1 420

Variable Cost

Feeds	*Quantity (kg)*	*Variable cost (N.Kr.)*	
		Per unit	*Total*
Dry feed—pelleted	40	2·20	88
Trash fish	400	1·00	400
Shrimp waste	50	1·00	50
Total			538

Others	*Quantity*	*Variable cost (N.Kr.)*		*Income (N.Kr.)*
		Per unit	*Total*	
Fingerlings	50 fish	2·00	100	
Veterinary assistance			20	
Insurance			100	
Packing			40	
Freight			20	
Ice			5	
Miscellaneous			10	
Total			295	833
Contribution				587

Conditions:
(*i*) period of growth—3 years
(*ii*) labour—11·5 hours
(*iii*) volume of water—13 kg/m^3
(*iv*) cost—N.Kr. 25/hour

Annex III

Rentability Budget for 1975

Type of product	*Quantity (kg)*	*N.Kr./kg*	*Sales*	*Variable production cost*	*Variable labour cost*	*Total variable cost*	*Contribution*	*Labour hours*	*Maximum volume m^3 water*	*Contribution*	
										Per hours	*m^3*
Rainbow trout	100 000	14·20	1 420 000	833 000	287 500	1 120 500	299 500	11 500	7 700	26·00	3·90
Salmon	60 000	23·00	1 380 000	567 000	312 500	879 500	500 500	12 500	6 000	40·00	8·34
Total	160 000	17·50	2 800 000	1 400 000	600 000	2 000 000	800 000	24 000	13 700	33·30	5·84

Fixed cost: N.Kr. 450 000
Profit: N.Kr. 350 000

Degree of contribution: $\frac{800\,000 \times 100}{2\,800\,000} = 28{\cdot}8\,\%$

Break-even point: $\frac{450\,000 \times 100}{28{\cdot}8} = 1\,573\,000$

Security margin: $\frac{(2\,800\,000 - 1\,573\,000) \times 100}{2\,800\,000} = 43\%$

Annex IV

Survey of Operation (in N.Kr. '000)

Income and cost	*Result last year*	*Result this year*	*Budget*	*Deviation from budget*
Operating income	2 200	2 500	2 800	300
Variable production cost	1 300	1 375	1 400	25
Labour cost	450	500	600	100
Variable cost	1 750	1 875	2 000	125
Contribution	450	625	800	175
Fixed cost	350	415	450	35
—salaries	60	65	70	5
—indirect cost	145	200	220	20
—interest on debts	100	100	110	10
—depreciation	45	50	50	0
Profit	100	210	350	140

Assets/liabilities/equity	*Balance*		*Flow of funds*		
	Beginning	*End*	*Use*	*Source*	
Current assets	160	65		95	
Stocks	1 130	1 515	385		
Fixed assets cost	320	420	100		
Total	1 610	2 000			
Short-term liabilities	530	700		170	
Long-term liabilities	640	600	40		
Equity	290	500		210	Cash flow
Depreciation accumulated	150	200		50	Cash flow
Total	1 610	2 000	525	525	

Production, employees, capacity

Quantity produced:	160 000 kg
Volume of water:	137 000 m^3
Man-hours/year:	
—variable	24 000
—administration	2 000
	26 000
Maximum production capacity:	200 000 kg

Annex V

Key values

Return on investment:

$$\frac{(210 + 100)100}{(2000 + 1610)/2} = 17{\cdot}2\,\%$$

Ability to pay wages:

$$\frac{(210 + 65 + 500)}{26\,000} = \text{N.Kr. } 29{\cdot}81/\text{hour}$$

Investment per yearly man-hours:

$$\left(\frac{2000 + 1610}{2}\right)\frac{2000^a}{26000} = \text{N.Kr. } 138000$$

Investment per kg produced:

$$\left(\frac{2000 + 1610}{2}\right)\frac{1}{16\,000} = \text{N.Kr. } 11.28/\text{kg.}$$

Production per yearly man-hours:

$$\left(\frac{160\,000}{26\,000}\right)\cdot 2\,000^a = 12\,300\text{ kg}$$

Production per unit volume of water:

$$\frac{160\,000}{13\,700} = 11{\cdot}7\text{ kg/m}^3$$

Utilization of capacity:

$$\left(\frac{160\,000}{\quad}\right)100 = 80\%$$

[a] Yearly man-hours per employee = 2 000 hours

Definition of key values

The most important indicator for measuring the profitability is the return on investment. This indicator relates the profit in the enterprise to the capital used and is defined as 'return on investment before taxes':

$$\frac{\text{Net profit before taxes + interest on debts, gross}}{\text{Total investment}}$$

As will be noticed, interest on debts is added to the profit. This makes comparison between enterprises with different financial situations and rates of interest more meaningful. Total investment includes not only fixed assets but stock and other current assets. The total investment should be the average of that at the beginning and the end of the period investigated. Return on investment in relation to the contribution methods is graphically illustrated in Fig. 1. From the point of view of the fish farmer and his employees the ability to pay wages is of special interest. This concept may be defined thus:

Ability to pay wages per yearly man-hour:

$$\frac{\text{Net profit before taxes + wages and salaries}}{\text{Total number of man-hours}}$$

The total number of man-hours should also include all unpaid labour, *eg*, the family of the owner. This measure can easily be compared with that of other alternative occupations in a region, *eg*, fishing, agriculture or industry. The following key values explain in more detail the two values just mentioned.

Production per yearly man-hour is a measure of the efficiency of the production. Production in kg per volume or surface area of water is a measure of the utilization of the ponds. Whether the volume of water or area of water surface should be chosen will depend on the kind of fish culture practised. Production in kg is defined as:

> Sales of fish + increase or − decrease in stock of fish, *ie* the same quantity from which the operating income is calculated

By utilization of capacity is meant the calculated maximum production (in kg) in relation to the production achieved (in kg) for the year under consideration. Other key values are financial measures regarding rentability, liquidity and solvency. The most common are:

(*i*) Acid test

$$= \frac{\text{Most liquid current assets}}{\text{Short-term liability}}$$

(*ii*) Average interest rate on liabilities

$$= \frac{\text{Interest on debts, gross}}{\text{Total liabilities}}$$

(*iii*) Equity as percentage of total capital

$$= \frac{\text{Equity}}{\text{Total capital}}$$

(*iv*) Capital turnover

$$= \frac{\text{Cash and credit sales of goods and services}}{\text{Total capital}}$$

(*v*) Profit margin

$$= \frac{\text{Net profit before taxes + interest on debts, gross}}{\text{Cash and credit sales of goods and services}}$$

(*vi*) Return on capital (already explained)

(*vii*) Return on equity

$$= \frac{\text{Net profit after taxes}}{\text{Equity}}$$

(*viii*) Working capital as percentage of total capital

$$= \frac{\text{Current assets − short-term liabilities}}{\text{Total capital}}$$

5 References

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Chapter III Culture of Crustaceans

Progrès dans les Techniques d'élevage des Crevettes et la Production de Juveniles

J. Perrot

Résumé
L'étude fait le point des progrès accomplis ces dernières années dans les techniques d'élevage des crevettes de mer (pénaeides) et des crevettes d'eau douce (*Macrobrachium*) à l'échelle mondiale.

En ce qui concerne les élevages larvaires de pénaeides à partir de femelles prises dans le milieu naturel, la méthode japonaise en grands volumes avec 'bloom' algal est complétée par la méthode américaine de culture séparée d'algues monospécifiques pour une alimentation contrôlée à haute densité. On cherche à disposer d'une alimentation artificielle appropriée dès les premiers stades larvaires.

La maturation et la ponte de géniteurs captifs a été obtenue pour plusieurs espèces de pénaeides en Polynésie et en France métropolitaine. Les élevages larvaires de crevettes d'eau douce ne posent plus de problèmes de principe, mais doivent être optimisés.

Pour les crevettes de mer, les techniques de grossissement semi-intensif, déjà opérationnelles en alimentation naturelle, ont bénéficié de la mise au point d'aliments composés, à partir des recherches de base sur les besoins nutritionnels des espèces concernées. Dans la conduite des élevages de cette nature, dont les facteurs principaux d'environnement sont maintenant bien connus, l'importance tenue par le sédiment a été mise en évidence. Par ailleurs, d'intéressantes recherches sont en cours au Japon et aux Etats-Unis sur le grossissement intensif. Le grossissement des crevettes d'eau douce n'entraîne pas de difficultés fondamentales mise à part la très grande hétérogénéité de la croissance.

Les problèmes pathologiques principaux des crevettes concernent à l'heure actuelle surtout les élevages larvaires et post-larvaires. L'identification des agents pathogènes a beaucoup progressé.

La technologie des élevages semi-intensifs en bassins en terre de petites dimensions (inférieurs à 10 ha) donne des résultats homogènes, à rendements limités (3 tonnes/ha par cycle). La technologie d'élevage intensif est encore au stade des recherches.

En conclusion, les progrès accomplis récemment, notamment en généralisant la possibilité de l'élevage, devraient entraîner une nouvelle phase de développement, en particulier dans les pays tropicaux.

Progress in shrimp culture techniques and the production of juveniles
Abstract
The study sums up the progress achieved during the last few years in culture techniques of saltwater shrimps (penaeids) and freshwater shrimps (*Macrobrachium*) on a worldwide scale.

As far as the culture of penaeid larvae from females caught in the natural environment is concerned, the Japanese method of using large quantities of algal 'bloom' is supplemented by the American method of separate culture of monospecific algae for controlled feeding at high densities. An attempt is being made to provide suitable artificial feeding from the first larval stage.

The maturation and the deposition of spawn from captive broodstock has been obtained for several species of penaeids in Polynesia and in metropolitan France. The culture of freshwater shrimp larvae no longer causes any fundamental difficulties but should be improved.

For saltwater shrimps, the technique of semi-intensive fattening, already operational in natural feeding, has benefited from the development of blended foods, from basic research on the nutritional needs of the species concerned. In this type of shrimp culture, where the main environmental factors are well known, the importance of sediment has been clearly shown. Moreover, useful research is under way in Japan and the United States on intensive fattening. The fattening of freshwater shrimps does not entail any fundamental difficulties apart from the great heterogeneity of their growth.

At present the main problems of shrimp pathology are concerned with the culture of larvae and post-larvae. Great progress has been made in the identification of pathogenic agents.

The technology of semi-intensive culture in small-sized earth pools (less than 10 ha) gives homogeneous results, with limited yields (3 tons/ha per cycle). The technology of intensive culture is still in the research stage.

In conclusion, progress achieved recently, especially in generalizing culture possibilities, should lead to a new phase of development, particularly in tropical countries.

Progresos en las técnicas de cría de camarones y producción de formas juveniles
Extracto
En el estudio se señalan los progresos de las técnicas de cría de camarones marinos (peneidos) y camarones de agua dulce (*Macrobrachium*) en todo el mundo en estos últimos años.

Por lo que se refiere a la cría de larvas de peneidos a partir de hembras capturadas en su ambiente natural, el método japonés de cría en grandes volúmenes con floraciones de algas se suplementa con el método americano de cultivo separado de algas monoespecíficas para alimentar a los camarones en régimen controlado de elevada densidad. Se intenta lograr una alimentación artificial adecuada desde las primeras fases larvales.

En Polinesia y en Francia (metropolitana) se ha conseguido hacer llegar a la madurez a progenitores, en cautividad, de varias especies de peneidos, que posteriormente procedieron a la puesta. La cría de larvas de camarón de agua dulce no plantea ya problemas en principio, pero debe optimizarse.

Por lo que se refiere a los camarones de mar, las técnicas de crecimiento semi-intensivo, ya utilizadas con alimentación natural, han podido mejorarse gracias a la preparación de alimentos compuestos como resultado de las investigaciones básicas realizadas sobre las necesidades nutricionales de las especies en cuestión. Se ha demostrado la importancia de los sedimentos en este tipo de cría, cuyos factores ambientales principales son en la actualidad suficientemente conocidos. En el Japón y en los Estados Unidos se están realizando investigaciones interesantes sobre crecimiento intensivo. El engorde de los camarones de agua dulce no plantea dificultades fundamentales, aparte la enorme heterogeneidad de su crecimiento.

En la cría de camarones, los problemas patológicos principales se concentran en la cría de fases larvales y post-larvales. La identificación de los agentes patógenos ha progresado mucho.

La cría semi-intensiva en estanques de pequeñas dimensiones (menos de 10 ha) permite obtener resultados homogéneos, con rendimientos limitados (3 toneladas/ha por ciclo). La tecnología de cría intensiva está aún en fase de investigación.

En conclusión, los progresos logrados recientemente, sobre todo generalizando las posibilidades de la cría de camarones, favorecerán una nueva fase de desarrollo de esta industria, en especial en los países tropicales.

1 Introduction

Le présent document a pour objet de faire le point des techniques actuelles d'élevage des crevettes dans de monde, en essayant de dégager les traits essentiels d'un nombre considérable d'informations dont on va s'efforcer d'effectuer une synthèse critique.

Mais avant d'aborder les principaux problèmes que nous aurons à considérer, nous aimerions présenter trois séries d'observations servant à mieux situer les développements ultérieurs.

1.1 *Orientation du document*

Le but visé ici est de réaliser un document exploitable par tous. Pour qu'il en soit ainsi, on s'est efforcé de donner aux questions traitées l'importance respective qu'elles méritent dans la seule perspective de déboucher sur des élevages économiquement rentables, et capables de progrès. Les points de vue scientifique ou technique sont par conséquent subordonnés à une vision qui les dépasse, en les englobant. Il est en effet relativement aisé de réaliser la presque totalité du cycle biologique de la crevette, de quelque espèce que ce soit, dans les conditions du laboratoire; il l'est déjà moins de le faire sur le terrain à des dimensions significatives; il l'est encore moins d'ordonner et d'optimiser à ce niveau les différents facteurs pour en faire, non plus un objet de recherche, mais une activité économique susceptible de

développement. C'est pourquoi nous n'omettrons pas d'indiquer soigneusement dans la suite de ce document les *dimensions* et l'*environnement* des résultats obtenus en essayant de les classer en trois grandes catégories correspondant elles-mêmes à trois types d'installations assez aisément différenciables: recherche en laboratoire, expérimentations de terrain dans des installations pilotes, enfin fermes commerciales[1].

1.2 *Espèces prises en considération*

Historiquement l'élevage des crevettes de mer s'est développé dans la zone indo-pacifique où il est pratiqué depuis de nombreuses années (Bardach, Ryther et McLarney, 1972) selon des modalités simples; il a été entrepris au Japon avec un support scientifique et technique de grande qualité permettant d'atteindre un haut degré de contrôle et des rendements prometteurs (Fujinaga, 1969; Shigueno, 1972). Dans les deux cas, les espèces cultivées, dominantes dans le milieu naturel, ont été des crevettes pénaeides: *Penaeus monodon* aux Philippines, *P. japonicus* au Japon essentiellement. Compte tenu des caractéristiques très favorables des pénaeides pour l'élevage (croissance rapide, haute fécondité, bonne résistance générale aux variations de l'environnement, enfin très bon accueil du marché), l'effort principal d'aquaculture de la crevette est actuellement axé sur ce groupe. Outre *P. monodon* et *P. japonicus* déjà cités les pénaeides faisant l'objet des principales recherches ou expérimentations sont surtout *P. aztecus, P. setiferus, P. duorarum* et *P. vanameii* dans le Golfe du Mexique, *P. brasiliensis* au Brésil, *P. orientalis* en Corée, *P. merguiensis, P. semisulcatus* dans la zone Pacifique, *P. kerathurus* en Atlantique ouest et Méditerranée, *P. indicus* dans l'Océan Indien. La plupart de ces espèces s'enfouissent dans le sédiment, certaines à un degré moindre comme *P. merguiensis*, cependant toutes sont suffisamment proches du point de vue des exigences physiologiques pour que les techniques d'élevage comprennent un domaine commun assez étendu. Les pénaeides sont des crevettes d'eaux chaudes. Dans le but de disposer d'espèces pouvant être élevées à l'extérieur en eaux froides ou tempérées, certains travaux ont été conduits, en Angleterre, en France et au Japon, sur plusieurs caridées d'eau de mer en particulier *Palaemon serratus, Pandalus platyceros* et *Pandalus borealis*. Nous n'y ferons référence qu'à titre secondaire, un certain nombre d'obstacles rendant les perspectives d'élevage de ces espèces assez peu favorables, au moins dans l'avenir immédiat. Par contre elles ont servi de matériel de travail pour mettre au point certaines techniques en particulier en matière de synchronisme des pontes et d'élevage larvaire.

Un intérêt considérable est porté depuis quelques années en zone tropicale aux crevettes d'eau douce, *Macrobrachium*, très appréciées par les populations d'Océanie et d'Amérique de Sud en particulier où plusieurs espèces existent dans le milieu naturel. Leur élevage a largement bénéficié des travaux effectués sur les pénaeides, spécialement en ce qui concerne la reproduction, si bien qu'il apparaît actuellement très prometteur au moins dans un certain cadre que nous essayerons de préciser.

[1] Le fait que dans la plupart des cas on suive cette séquence dans cet ordre montre à l'évidence que nous ne sommes qu'au tout début de l'histoire de l'élevage des crevettes. Le principe suivant lequel c'est au terrain à commander la nature et la hiérarchie des recherches n'est pas encore applicable.

En définitive, dans la suite de ce travail, il s'agira essentiellement de mettre en évidence les progrès des techniques se rapportant d'une part à la culture des pénaeides, en ce qui concerne les crevettes de mer, d'autre part à celle des *Macrobrachium* pour les crevettes d'eau douce. Le fait que l'on ait choisi de présenter les problèmes correspondants d'après leur nature (reproduction, grossissement, pathologie, etc.) conduira du même coup à mettre en évidence sous chaque rubrique les similitudes et les différences.

1.3 *Bases et limites du document*

En ce qui concerne la connaissance des faits et des techniques, comme celle des recherches et expérimentations en cours dans le monde entier, nous sommes redevables à tous ceux qui ont bien voulu répondre à notre appel et actualiser considérablement la documentation dont nous disposions. Qu'ils soient ici très vivement remerciés, même si la nécessité de faire 'bref' nous conduit dans le corps du texte à réduire les références au strict indispensable. D'un autre côté l'experience concrète des problèmes et des difficultés de chaque jour, et si je puis dire, la philosophie de l'élevage en résultant, synthétise au sein du CNEXO huit années de travail. Elle vient directement du suivi méthodique de recherches et expérimentations de terrain effectuées tant en France qu'en zone tropicale sur une dizaine d'espèces de pénaeides et sur deux caridées: *Palaemon serratus* en France, *Macrobrachium rosenbergii* à Tahiti. Sous cet éclairage, la présente synthèse est celle d'une équipe bien insérée dans un tissu de coopération internationale et d'aide mutuelle qui valorise heureusement les travaux accomplis.

2 Les problèmes d'approvisionnement en juvéniles

La base de tout élevage est de disposer d'un approvisionnement en juvéniles en quantités voulues, de qualité voulue, au moment voulu. Les moyens d'approvisionnement employés jusqu'ici, ont comporté par ordre de technicité croissante: (*i*) la capture de juvéniles dans le milieu naturel; (*ii*) la production de post-larves à partir de femelles gravides prises dans le milieu naturel; (*iii*) la production de post-larves à partir de géniteurs d'élevage.

2.1 *Approvisionnement en juvéniles de pénaeides*

2.1.1 *Capture dans le milieu naturel.* C'est la méthode la plus simple. Elle est utilisée depuis fort longtemps dans la zone indo-pacifique. On peut même souvent à peine parler de capture puisque les jeunes crevettes entrent naturellement dans les estuaires, les étangs côtiers, les mangroves à certaines périodes de l'année, et dans des conditions de marée et de lunaison bien déterminées. Il suffit donc de favoriser cette entrée dans les bassins d'élevage chaque fois que leur situation et leur agencement le permettent. Dans les autres cas, on pêche les juvéniles à l'aide de filets appropriés.

Cette méthode peut convenir pour des élevages extensifs dans des sites particulièrement favorables. Elle peut aussi être utilisée lorsque l'on désire faire une expérimentation préalable de grossissement avec des espèces locales, avant d'édifier une écloserie. Mais ses limites sont vite atteintes, car elle ne peut répondre aux exigences d'un élevage industriel. D'une part, en effet, les quantités capturées restent aléatoires (à titre d'exemple une expérience répétée deux années de suite en Guyane à l'ouvert du marais de Mana a montré que des pêches systématiques aux mêmes endroits

avec les mêmes apparaux dans une zone considérée comme particulièrement favorable avaient des rendements qui pouvaient varier de 1 à 30). D'autre part cette pêche est limitée à une certaine période de l'année ce qui conduit à ne pouvoir faire au mieux qu'un cycle de production par an. De plus il n'existe qu'une homogénéité très relative entre les juvéniles capturés qu'il s'agisse de la taille, ou même de l'espèce lorsque plusieurs espèces cohabitent dans le milieu naturel. Enfin la date de début d'élevage est impérativement fixée sans qu'elle coïncide forcément avec la période la plus souhaitable.

2.1.2 *Production de post-larves à partir de femelles gravides prises dans le milieu naturel.* Pour échapper à tout ou partie de ces contraintes, un grand effort de recherche et de technologie associées a été déployé d'abord au Japon puis dans un certain nombre de pays pour obtenir les juvéniles nécessaires à partir de la ponte de femelles gravides prises dans le milieu naturel et de l'élevage contrôlé des larves[1]. Les premiers succès ont été obtenus par Fujinaga et ses collaborateurs qui ont établi, puis perfectionné une méthode complète d'élevage de *Penaeus japonicus*, et en particulier la production de juvéniles, à partir des années quarante (Fujinaga, 1942).

Ramenée à l'essentiel, la méthode est la suivante: les femelles gravides sont obtenues de la pêche commerciale, si possible à partir de chalutages courts. Après tri et vérification du degré de maturité, elles sont introduites dans des bassins de 60–200 m^3 où la ponte s'opère naturellement dans l'une des deux nuits qui suivent. Chaque femelle pond plusieurs centaines de milliers d'œufs. Les correspondances entre le nombre de femelles, le volume des bassins et la quantité d'œufs à traiter ont été optimisées expérimentalement, en comptant statistiquement sur la ponte d'une femelle sur deux. Après la deuxième nuit, les mères sont retirées. L'éclosion a lieu une quinzaine d'heures après la ponte. Alors commence l'élevage larvaire. L'eau est de l'eau de mer naturelle, pompée et filtrée, maintenue par chauffage à une température comprise entre 25°C et 30°C avec une salinité proche de 30‰. La densité initiale des larves au stade 'nauplius' est au plus de 100/l. La quantité d'eau est augmentée ensuite régulièrement de telle façon que le volume d'élevage ait doublé au dernier stade 'mysis'. L'aération est assurée de façon permanente. Les larves subsistent sur leurs réserves vitellines pendant les stades 'nauplius', mais elles doivent être nourries dès le premier stade 'zoé'. Le phytoplancton nécessaire leur est fourni en fertilisant l'eau de mer dès après l'éclosion par l'introduction quotidienne de quantités appropriées de sels minéraux qui provoquent un 'bloom' d'algues unicellulaires, et ce, jusqu'au dernier stade 'mysis' et même selon certaines pratiques, au-delà.

De la première 'mysis' jusqu'à la post-larve (P), la nourriture est ensuite composée de 'nauplii' d'*Artemia salina*, de rotifères, et plus récemment d'un composé de soja (soybean cake) mis au point par Hirata *et al.* (1974). Puis les post-larves auxquelles on donne à partir du 5 ou 6ème jour de la chair de mollusques finement broyée ou une nourriture composée suivant une formule appropriée séjournent encore de 10 à 20 jours dans l'écloserie avant d'être transportées dans des bassins extérieurs pour y commencer leur grossissement, à un poids de l'ordre de la dizaine de milligrammes.

L'ensemble du processus, les expériences correspondantes, et les modalités détaillées de conduite des opérations sont exposés dans le récent livre de K. Shigueno, 'Shrimp culture in Japan' (Shigueno, 1975). La méthode japonaise a servi de base à tous les travaux ultérieurs et a été utilisée avec succès pour les espèces de pénaeides abordées. Un certain nombre de modifications ont cependant été soit imposées dans certains cas, soit considérées comme des perfectionnements.

Tout d'abord le processus du 'bloom' suppose que l'eau de mer dont on se sert contient les souches des algues unicellulaires les plus appropriées et que le développement algal reste satisfaisant sans contrôle possible autre qu'une action de réponse dans un délai incertain à la quantité de sels minéraux, à l'éclairement et au renouvellement partiel de l'eau. Or, selon les régions du monde envisagées, la qualité de l'eau de mer et la composition du phytoplancton varient assez largement si bien que les résultats peuvent être très différents. C'est pourquoi des efforts ont été entrepris, spécialement aux Etats-Unis, pour d'une part intensifier le contrôle de la nourriture algale et d'autre part, augmenter la densité des élevages larvaires.

L'essentiel de la méthode actuelle a été mis au point par l'équipe de Galveston (Mock et Neal, 1974). Les algues sont cultivées séparément de façon monospécifique dans de l'eau de mer artificielle de composition constante. Le couple algal le plus souvent préparé et distribué est *Skeletonema costatum—Tetraselmis*, mais d'autres sont envisageables (à Tahiti, le COP utilise *Phaeodactylum—Tetraselmis*). Bien entendu, la culture des algues est conduite en continu de façon telle que le volume total de la production couvre les besoins de la période d'élevage larvaire avec mise en réserve des algues produites en dehors de cette période. Pour cela les algues non immédiatement utilisées sont concentrées et réfrigérées suivant une technique qui s'est généralisée dans tous les laboratoires et écloseries.

Qu'elles soient d'origine fraîche, ou congelées, les algues ne sont introduites dans les bacs d'élevage qu'en fonction des besoins préalablement calculés. L'équipe de Galveston utilise par ailleurs des bacs à fond conique de petite capacité (2 m^3) soumis à une aération intense. La possibilité de distribuer de façon absolument rigoureuse une nourriture contrôlée (algues, puis 'nauplii' d'*Artemia*, etc.) permet d'obtenir une densité d'élevage plus grande ainsi qu'un meilleur taux de survie. D'après Mock (1974), le taux de survie de l'œuf à la post-larve qui oscille entre 10 et 30% avec la méthode japonaise atteint de 70 à 80% avec la méthode de Galveston. Les comparaisons ne sont peut-être pas entièrement valables car l'élevage larvaire s'interrompt à P2-P3 à Galveston tandis qu'il continue généralement jusqu'à P20-P30 au Japon; surtout les dimensions des opérations ne sont pas les mêmes.

La méthode japonaise a le grand mérite de la simplicité et de l'efficacité sur des grands nombres. Des milliards de post-larves ont été produites depuis quinze ans avec une fiabilité satisfaisante. Elle est particulièrement adaptée au contexte local. La méthode de Galveston, avec un rendement meilleur, serait moins coûteuse en investissements mais nécessite une main-d'œuvre plus qualifiée. Surtout elle est plus générale puisqu'indépendante, en quelque sorte, des

[1] Le développement des larves de pénaeides passe par les étapes suivantes: nauplius (5 à 6 stades), zoé (3 stades), mysis (3 stades), puis la larve devient post-larve. Le temps nécessaire pour franchir la totalité des étapes larvaires de l'éclosion à la post-larve est de l'ordre d'une dizaine de jours.

conditions locales. En tout état de cause, l'on peut admettre qu'il n'y aurait plus de problèmes techniques majeurs en ce qui concerne les élevages larvaires si les menaces pathologiques étaient surmontées (voir sec. 4.1).

Restent bien sûr les problèmes économiques, c'est-à-dire la nécessité d'améliorer encore les techniques afin de les rendre plus fiables, et en quelque sorte plus 'banales' pour diminuer les frais d'un personnel spécialisé. Dans cette perspective, plusieurs directions de recherches doivent être suivies. La première est de dépasser à la fois le 'bloom' ou la culture sélective d'algues unicellulaires pour disposer d'une alimentation artificielle adaptée. L'utilisation au Japon de poudre de soja (soybean cake) (Hirata *et al.*, 1974) et les expérimentations sur aliment composé à base de céphalopode vont dans ce sens. Cette recherche rejoint d'ailleurs une recherche plus générale sur les élevages larvaires de crustacés et poissons, et des progrès ont été aussi accomplis en France dans cette direction.

Une seconde direction de recherche est de progresser dans la connaissance fondamentale des besoins alimentaires des différents stades larvaires, et surtout des conditions optima d'environnement. En particulier, à partir du moment où la nourriture est distribuée (*Artemia*, puis mollusque ou nourriture composée), le nombre des repas et leur intervalle, en conjonction avec l'éclairement, paraissent jouer un rôle important. De même il n'y a encore que peu d'observations, en dehors de considérations globales, sur l'influence de la salinité aux stades larvaires.

Enfin il y a lieu de privilégier les productions importantes pour diminuer les coûts relatifs. Le transport de femelles gravides lorsqu'il est d'une certaine durée, s'est révélé décevant, ne permettant pas d'alimenter des éclo series trop éloignées des lieux de capture (les décalages du cycle d'éclairement et donc les écarts de longitude paraissant plus ressentis que les écarts de latitude). Par contre le transport de post-larves entre P5 et P20 ne présente pas de difficultés particulières. C'est ainsi que des transports de post-larves de *P. japonicus* (de l'ordre du million de post-larves) sont régulièrement effectués depuis cinq ans entre le Japon et la France avec des durées de transport qui ont pu atteindre quarante heures, et des taux de survie, dans les plus mauvais cas, supérieurs à 50%.

Il en résulte un intérêt certain à augmenter la taille des écloseries pour leur faire desservir le plus grand nombre possible de fermes de grossissement. Cette tendance ne pourra qu'être renforcée lorsque pourront être envisagées les premières mesures de sélection génétique. Notons encore que les exemples cités ne sont pas exhaustifs et que des travaux de valeur concernant les élevages larvaires de différentes espèces de pénaeides ont été effectués depuis déjà un certain nombre d'années en Grande-Bretagne à Conwy et plus récemment au Mexique à l'Université de Puerto Peñasco à Sonora ainsi qu'en Argentine à Mar del Plata, au Brésil à Natal, aux Philippines, etc.

Signalons enfin dans les travaux français, et bien qu'il ne s'agisse pas de pénaeides mais de caridées, qu'au Centre océanologique de Bretagne à Brest une équipe a réussi d'une part à synchroniser, d'autre part à avancer les éclosions d'œufs de femelles de *Palaemon serratus* en cours de développement embryonnaire.

2.1.3 *Production de post-larves à partir de géniteurs d'élevage.* La production de juvéniles à partir de femelles capturées dans le milieu naturel, acceptable pour des élevages proches des aires de distribution des espèces concernées et des lieux de pêche importants, n'en présente pas moins toute une série d'inconvénients. D'une part, en effet, de tels élevages restent dépendants des périodes de reproduction naturelle des espèces en cause et les programmes peuvent eux-mêmes être perturbés par des conditions météorologiques peu favorables à des chalutages spécialisés. D'autre part on ne peut envisager d'élevages dans des régions où n'existent pas de stocks naturels d'espèces intéressantes, ou pour des espèces non représentées dans ces stocks. Enfin, et peut-être surtout, l'approche génétique est impossible bloquant ainsi l'une des voies les plus prometteuses pour l'amélioration de quelque élevage que ce soit.

D'où l'intérêt considérable porté actuellement aux problèmes de maturation et de ponte de crevettes pénaeides en captivité. Dans ce domaine également Fujinaga a été le premier à rendre compte succintement de l'obtention en captivité de plusieurs générations de *Penaeus japonicus*, et noté une diminution considérable du nombre d'œufs pondus à chaque génération. Les travaux n'avaient pas été ensuite poursuivis avec insistance au Japon compte tenu de la facilité pour les éleveurs de ce pays à se procurer des femelles matures dans le milieu naturel. Dans la période récente, au contraire, un certain nombre de travaux et d'expérimentations ont été consacrés en divers pays à la résolution de ces problèmes.

Les résultats les plus significatifs, à notre connaissance, ont été obtenus en France, au Centre Océanologique de Polynésie (Aquacop, 1974) d'abord, puis à Maguelone sur la Méditerranée, et enfin au Centre Océanologique de Bretagne pendant l'été 1975 (résultats inédits).

On distinguera dans ce qui suit d'une part les observations effectuées en Polynésie et les résultats obtenus, et d'autre part l'étude des facteurs de maturation telle qu'elle a été menée en France. On essayera d'en tirer ensuite quelques conclusions avant d'aborder le problème génétique.

2.1.3.1 Observations et résultats en Polynésie. En Polynésie, la maturation et la ponte de géniteurs captifs ont été obtenues de façon régulière sur *Penaeus merguiensis* à partir de septembre 1973, puis à un moindre degré, le stock de géniteurs étant beaucoup plus réduit, sur quatre autres espèces *Metapenaeus ensis, P. semisulcatus, P. japonicus* et *P. aztecus*.

La majorité des maturations a été obtenue dans des bassins circulaires de 12 m^3 (profondeur 1 m) à fort renouvellement d'eau par l'intermédiaire d'un fond drainé. La température varie au cours de l'année de 26°C à 29°C, la salinité est pratiquement constante (34 à 35‰), le pH est voisin de 8,2, la durée d'insolation est de 11 heures en période hivernale, et 15 heures en période estivale; 200 à 300 crevettes sont maintenues dans chaque bassin avec un sex-ratio 1:1 bien qu'il semble qu'un pourcentage de 25% de mâles soit suffisant pour obtenir une fécondation régulière.

Sur *P. merguiensis* (environ un millier de pontes obtenues), les maturations s'observent tout au long de l'année pour les femelles de 6 g et plus. La fécondation est réalisée avant tout signe extérieur de maturation. Des critères précis basés sur la croissance et la couleur des ovaires permettent de sélectionner chaque soir les femelles mûres. La ponte a alors lieu dans la nuit ou la nuit suivant l'isolement des animaux. Les premiers bassins étaient recouverts d'une

toile ombrée, réduisant de 60% l'éclairement.

Les crevettes se tenaient tout le jour dans les parties les plus obscures au pied des parois. Une couverture à 90% a donné des maturations plus nombreuses. Une expérience avec des bassins maintenus complètement à l'ombre pour moitié et à 60% pour l'autre moitié a montré que les animaux se tenaient toute la journée dans la partie ombragée et que le taux de maturation était élevé.

Les maturations ont été obtenues avec plusieurs types d'aliments: (*i*) granulés fabriqués localement à base de chair de mollusque (troca) et de farine de poisson; (*ii*) granulés japonais 'Shigueno'; (*iii*) alimentation mixte: granulés—déchets de bonite.

Le nombre d'œufs pondus est très variable, il croît avec la taille, de 3–4 000 œufs pour une femelle de 6 g, 20 000 pour une femelle de 15 g. Dans le milieu naturel, Tuma (1967) signale 100 000 œufs pour les plus grosses femelles de cette espèce (50–70 g) qui n'a donc qu'une fécondité moyenne. Les taux d'éclosion se sont situés entre 10 et 60%. Plus de 500 000 post-larves ont été obtenues et mises en grossissement.

Des maturations et pontes de la quatrième génération en captivité donnent des résultats stables. Sur les autres espèces, les points importants mis en évidence ont été la constatation d'un âge différent selon l'espèce pour la première maturation, et la nécessité de l'ablation d'un pédoncule oculaire pour obtenir la maturation de *P. aztecus*.

2.1.3.2 Expérimentations en France métropolitaine. Une expérience de maturation contrôlée a été entreprise à Maguelone sur les bords de la Méditerranée, à partir de décembre 1973, sur des géniteurs de *P. japonicus* provenant d'un élevage réalisé l'été 1973 à partir de post-larves importées du Japon. L'expérience a porté sur 320 animaux répartis en nombre égal dans 4 bassins circulaires de 5 m de diamètre sous une serre en plastique. Le but était de tester l'influence relative de deux remontées photopériodiques de 8 heures à 16 heures, l'une naturelle sur 6 mois, l'autre accélérée sur 3 mois en correspondance avec deux remontées thermiques de 15 à 24°C, l'une sur 6 mois et l'autre accélérée sur 3 mois, tous les autres facteurs restant constants. L'analyse de la vitellogenèse a été réalisée de façon continue par 4 voies complémentaires dont l'analyse microscopique des gonades et l'analyse des lipoprotéines de l'hémolymphe.

Des maturations ont été obtenues sur les deux programmes testés avec avance de 2 à 3 mois dans le cas de remontées photopériodique et thermopériodique associées. Un certain nombre de pontes ont suivi, les unes naturelles, les autres provoquées par un choc de pression.

L'extension de ces expériences à l'hiver et au printemps 1975 au Centre Océanologique de Bretagne par A. Laubier a permis d'obtenir selon une séquence entièrement contrôlée du point de vue température, photopériode, environnement et alimentation, des maturations, pontes naturelles et production de post-larves de *P. japonicus* (Laubier et Laubier, 1979).

2.1.3.3 Résultats acquis et perspectives. Les progrès accomplis ont bien entendu bénéficié des travaux effectués antérieurement ou simultanément par d'autres équipes, en particulier sur l'induction de la maturation par l'ablation du pédoncule oculaire (Arnstein et Beard, 1975), la détermination de la maturation par la couleur des ovaires (Brown et Patlan, 1974) et la maturation de *Penaeus californiensis* en captivité (Moore, Sherry et Montañez, 1974). D'ores et déjà l'on peut dire que ce problème difficile de l'obtention de post-larves à partir de géniteurs captifs, considéré comme l'une des clefs de l'extension des élevages de crevettes, est en voie de résolution.

Outre la possibilité effective d'obtenir des maturations contrôlées, suivies de pontes viables, on a mis en évidence les influences, au moins qualitativement appréciées, mais encore non interprétées du point de vue physiologique de la photopériode et de l'intensité lumineuse, de l'âge et du poids selon les espèces, de la température et en particulier de la rapidité de la remontée thermique, d'un antagonisme croissance-reproduction, et de l'évolution différente des géniteurs primipares et des géniteurs multipares.

Beaucoup de travail reste à faire aussi bien dans l'interprétation des premiers résultats et leur détermination quantitative, que pour répondre à beaucoup d'autres questions. Par exemple, à notre connaissance, la charge, la dimension optimum d'un bassin de géniteurs, l'alimentation, les variations de salinité, les conditions d'isolement (bruit en particulier), le renouvellement de l'eau et la profondeur du bassin (pression, etc.) n'ont fait l'objet d'aucune évaluation.

Dans ce domaine, comme dans bien d'autres auparavant, il y a lieu maintenant d'utiliser avec une grande rigueur la méthode factorielle, et à partir de la mise en évidence d'une réponse sans défaillance à la variation d'un facteur ou d'une synergie de facteurs, d'essayer de définir les mécanismes biologiques complexes qui sont impliqués. Alors seulement, on pourra disposer de façon fiable de la technologie appropriée.

2.1.3.4 Approche génétique. Peu de choses sont à dire à ce sujet, sinon que les travaux de génétique autres que fondamentaux ne pourront prendre leur essor que lorsque la question de la maturation des géniteurs en captivité sera complètement résolue. Cependant on signalera d'une part les recherches effectuées en Angleterre à Lowestoft sur les poissons (Purdom, 1972) dont la méthodologie pourra utilement servir le jour venu, et d'autre part la fertilisation *in vitro* d'œufs de *Penaeus aztecus* obtenue par les laboratoires de Galveston et Houston (Clark *et al.* 1973). La réussite de cette dernière expérimentation permet en particulier d'envisager ultérieurement l'hybridation des crevettes pénaeides.

2.2 *Approvisionnement en juvéniles de crevettes d'eau douce*

A l'heure actuelle, tous les élevages de crevettes d'eau douce concernent pratiquement la crevette d'eau douce originaire de Malaisie, *Macrobrachium rosenbergii*, laquelle a fait l'objet d'études très complètes depuis de nombreuses années en particulier par Ling (1969) et Fujimura (1967–74), et présente des caractéristiques biologiques intéressantes pour l'aquaculture.

La maturation, la fécondation et la ponte de *M. rosenbergii* en captivité ne présentent plus de difficultés. De plus, faisant partie du groupe des caridées, les femelles incubent leurs œufs après la ponte si bien que le transport de femelles vivantes et portant des œufs est relativement aisé même sur de longues distances. Aussi l'étude des stades larvaires en a-t-il été facilitée même dans des laboratoires éloignés de toute souche naturelle.

On sait précisément que dans la nature *M. rosenbergii* pond dans les estuaires et que les larves vivent en eaux saumâtres, en passant par onze stades successifs avant de donner des post-larves.

Afin de permettre des cultures de masse, l'attention s'est donc concentrée sur la méthodologie des élevages larvaires. Fujimura (1966) ainsi que Minamizawa et Morizane (1970) en avaient défini les principales exigences. En particulier ils établirent que dans leurs conditions opératoires les meilleurs taux de survie étaient obtenus avec des salinités de 6 à 12‰ et une température de 30°C. L'eau devait avoir un pH de 8,1 et une forte concentration d'algues vertes.

2.2.1 *Observations faites à Conwy, Grande Bretagne.* Forster et Wickins (1972) ont maintenu dans des conditions de laboratoire un stock de deux mâles et onze femelles desquels 500 000 larves viables ont été obtenues en 10 mois, avec un pourcentage final de survie, de l'œuf au juvénile, de 14%. Ils signalent le caractère encore aléatoire de l'élevage larvaire.

2.2.2 *Observations faites au Skidaway Institute à Savannah, E-U.* L'objectif de Sick et Beaty (1974) était d'établir les exigences spécifiques de la culture des larves de *M. rosenbergii* avec l'investissement minimum, ainsi que de mettre au point une formule de nourriture larvaire donnant le maximum de survie. Après étude, le choix s'est porté sur des bacs d'élevage coniques de 60 l. La salinité doit varier selon les stades larvaires (10–16‰). Les meilleurs résultats sont obtenus à des densités de 20–40 animaux/l et les nauplii d'*Artemia* doivent dépasser 0,7 mm pour obtenir les meilleurs taux de grossissement. Enfin parmi les différentes formules d'aliments composés testés, seul un régime d'*Artemia* séchés et congelés convient à tous les stades larvaires. Les larves atteignent la métamorphose en 18 jours avec un taux de survie de 57%. Ces expérimentations restent à l'échelle du laboratoire.

2.2.3 *Observations faites au Centre Océanologique du Pacifique à Tahiti.* A partir de reproducteurs importés en 1973 d'Hawaï, du laboratoire de Fujimura, on s'est proposé après avoir obtenu le premier cycle complet, de mettre au point une méthode de production de post-larves en grandes quantités, d'abord en bacs à fond conique de 500 l, puis en bacs de 2,5 m^3 à fond conique pour obtenir plus de 60 000 post-larves tous les 45 jours.

Les premiers résultats sont les suivants: (*i*) maturations, fécondations, pontes et éclosions, s'observent toute l'année dans les conditions de Tahiti; (*ii*) les techniques de maintien et de manipulation des reproducteurs ainsi que la technologie générale de l'élevage larvaire ne présentent pas en elles-mêmes de grandes difficultés. Dès la première année, 500 000 larves ont été produites et une première génération d'élevage obtenue, un million de larves ont été produites au premier trimestre 1975; (*iii*) un aliment particulier a été développé pour obtenir de bonnes maturations; (*iv*) il est possible en modifiant les températures de synchroniser les pontes de façon à procéder à des élevages homogènes.

Par rapport à la technique de Fujimura, aucune eau verte ou culture d'algue monospécifique n'est utilisée. Par ailleurs il semble préférable de pratiquer des cultures d'*Artemia* séparées afin de calibrer les tailles suivant les stades d'élevage. Enfin on a utilisé une méthode mixte consistant à pratiquer l'élevage en très forte densité (80 larves/l) jusqu'au stade VI et de continuer ensuite en bassin en béton de 7 m^3 à densité plus faible jusqu'à la métamorphose. Cependant, en 1975, un blocage de la métamorphose ainsi que des mortalités importantes sont survenues, surtout entre le 9ème et le 15ème jour, sans qu'on ait pu en déterminer véritablement la cause. Ces incidents retardent la normalisation des élevages larvaires.

2.2.4 *Discussion.* Les quelques exemples ci-dessus montrent que les techniques de reproduction et d'élevage larvaires de *M. rosenbergii* sont à peu près satisfaisantes à l'heure actuelle à l'échelle du laboratoire ou des installations-pilotes. A notre connaissance il n'existe pas de production de masse de l'ordre de 1 à 2 millions de post-larves tous les 45 jours, à part peut-être l'écloserie de Fujimura à Hawaï. Aussi les calculs de coût développés par Yung Cheng Sang (1974) pour une écloserie produisant annuellement 16 millions de juvéniles restent-ils encore assez théoriques.

En fait, deux problèmes majeurs ne sont pas résolus. Le premier, et le plus important, est la durée beaucoup trop longue qui existe, en fait, dans une production de masse entre l'apparition des premières post-larves et la métamorphose de la majorité des larves; le second concerne le caractère encore imprévisible de certains aléas, qu'on ne saurait rapporter à un problème de pathologie.

De tels problèmes demandent un effort de recherche certain. Si la crevette d'eau douce rencontre un accueil en général favorable sur le marché, la durée de son grossissement impose que la fourniture de post-larves puisse être assurée à un coût très bas, afin d'aboutir à un prix de revient total compétitif.

3 Les problèmes de grossissement

3.1 *Généralités*

Si l'approvisionnement en juvéniles dans des conditions de fiabilité et d'économie satisfaisantes conditionne la possibilité d'un élevage, c'est la capacité de conduire ces juvéniles jusqu'à la taille marchande avec un rendement suffisant de tous les facteurs de production qui fonde ou non la factabilité technique et économique de l'aquaculture. En ce qui concerne les crevettes, nous allons examiner cette question centrale en distinguant comme ci-dessus les problèmes des crevettes de mer de ceux des crevettes d'eau douce. Pour chacune des deux catégories nous choisissons de prendre en considération trois types d'élevages que nous appelons en première analyse élevage extensif, élevage semi-intensif et élevage intensif pour traduire à la fois le contrôle croissant exercé sur les facteurs du grossissement ainsi que l'augmentation des charges et rendements correspondants.

3.2 *Grossissement des crevettes pénaeides*

3.2.1 *Elevage extensif.* On considérera comme élevage extensif une forme d'élevage dans laquelle le contrôle de l'homme est réduit au minimum et n'intervient en particulier ni sur l'alimentation, ni sur le renouvellement et la qualité de l'eau; le meilleur exemple en est donné par les élevages traditionnels de crevettes (*Penaeus monodon* aux Philippines, et *Metapenaeus* en Malaisie) dans des bassins pris sur la mangrove et façonnés de manière artisanale. Les juvéniles entrent avec le flot ou sont pêchés dans les estuaires. Aucune nourriture n'est distribuée. Dans certains cas, un fertilisant organique est ajouté. Blanco (1972)

donne pour de tels élevages aux Philippines un rendement soit de l'ordre de 400 kg/ha sans fertilisation et de 900–1 000 kg/ha avec fertilisation.

Sous certains aspects au moins on peut rapprocher de ces élevages l'essai tenté aux Etats-Unis entre 1970 et 1973 par Marifarms Inc., dans une partie de West Bay à Panama City sur une superficie de 10 000 ha enclose par un filet de 5 km. Les résultats furent décevants (Kittaka, inédit), bien qu'une nourriture supplémentaire ait été distribuée. Le rendement global le meilleur ne dépasse pas 20 kg/ha/an. Si un certain nombre de crevettes s'échappèrent en franchissant le filet, il semble bien que l'impossibilité de supprimer efficacement les prédateurs ait été une cause non négligeable de l'échec. Et ceci reste vrai pour tous les élevages extensifs.

Plusieurs auteurs (Latapie, Broom et Neal, 1972; Kittaka et Murray, 1975) ont d'ailleurs mis en évidence que la présence de prédateurs ou de compétiteurs réduisait non seulement le taux de survie, mais aussi le taux de croissance.

Finalement, l'élevage extensif n'apparaît viable à l'heure actuelle qu'au voisinage immédiat de populations naturelles de crevettes, à la condition de se contenter de faibles rendements eux-mêmes très variables d'une année à l'autre.

3.2.2 *Elevage semi-intensif.* L'élevage semi-intensif correspond aux élevages japonais actuels. Réalisé généralement en bassins de terre de dimensions comprises entre 1 et 10 ha, il suppose un contrôle déjà poussé des facteurs nutritionnels et des facteurs d'environnement. Il aboutit à des rendements par cycle de l'ordre de 2–3 tonnes/ha.

Curieusement d'ailleurs, ce type d'élevage n'existe encore qu'au Japon. Il reste sensiblement au même niveau de développement, malgré la croissance du marché, sa proximité et les prix élevés pratiqués pour la crevette vivante. Partout ailleurs, on ne peut encore parler que d'installations pilotes, les quelques grands projets américains, soit directement aux Etats-Unis, soit en Amérique Centrale, n'ayant pas apporté la preuve de leur rentabilité.

(i) *Les facteurs nutritionnels.*

Comme dans la plupart des cas en aquaculture, l'alimentation des crevettes d'élevage a d'abord fait l'objet d'observations et d'expérimentations pratiques à partir des aliments naturels disponibles dans l'environnement côtier (poissons, mollusques, crustacés), puis de recherches de base sur les besoins alimentaires des animaux à différents stades de leur existence, celles-ci aboutissant à la mise au point d'aliments composés et à la définition de régimes alimentaires.

L'aliment naturel utilisé au Japon de façon courante depuis que Fujinaga a montré son efficacité dans l'élevage des crevettes consiste en chair de mollusque, clam et moule, dont on broie les coquilles. Dans les exploitations qui font du pré-grossissement, généralement pendant une durée d'une cinquantaine de jours après P20, la même nourriture est utilisée mais sans coquille et la chair est finement broyée, ce qui nécessite un important travail supplémentaire.

Le taux de conversion global constaté pendant la durée d'un élevage, c'est-à-dire en première approximation le rapport entre le poids de nourriture distribué et le grossissement correspondant des crevettes, se situe avec ce type de nourriture autour de 10, avec d'assez larges écarts.

Des expérimentations entreprises au Japon pour déterminer la préférence des crevettes entre plusieurs espèces d'animaux marins ont placé les clams en tête avec ensuite dans l'ordre la chair d'huître, les néréides, le poulpe, la chair de crevette, le gobie et le maquereau. De nombreuses autres expérimentations ont été faites en d'autres pays, à différentes dimensions. En France à Maguelone le grossissement d'environ une tonne annuelle de *P. japonicus* est effectué depuis 1972 avec du crabe vert broyé dans de bonnes conditions de croissance, avec un taux de conversion élevé, de l'ordre de 15.

En fait la crevette s'accommode d'un régime alimentaire éclectique; elle est aussi capable de chasser le zooplancton que de dépecer un cadavre, de brouter une algue ou d'ingérer la pellicule superficielle d'un sédiment sablo-vaseux comme d'assimiler la chair de n'importe quel animal marin. Le problème de l'aliment naturel est donc essentiellement, en ce qui concerne les mollusques, les crustacés, ou le poisson, un problème de disponibilité, de coût d'acquisition, et de coût de préparation d'une telle nourriture en fonction de son rendement.

Les *recherches* sur les besoins et le régime alimentaires des pénaeides ont fait de gros progrès dans les dernières années, dans le cadre d'études générales sur les mécanismes et les exigences nutritionnelles des crustacés. Il n'est pas possible dans le cadre de cette synthèse de mentionner tous ces travaux. Citons en particulier les équipes japonaises (Faculté des pêches de l'Université de Kagoshima), françaises (laboratoire Ecole Pratique des Hautes Etudes; Station Marine d'Endoume, Marseille), anglaise (Fisheries Experiment Station, Conwy), et américaine (National Marine Fisheries Service Biological Laboratory, Galveston), appliquées à ces problèmes.

L'on a ainsi mis en évidence le niveau et la qualité des protéines nécessaires, le métabolisme des lipides, l'équilibre en acides aminés, l'équilibre vitaminique, l'importance des minéraux sur les enzymes digestives, et l'importance des stérols.

A partir des résultats obtenus, des *aliments composés* ont pu être mis au point et font maintenant l'objet de ventes commerciales. Citons en particulier l'aliment développé d'après les travaux et expérimentations de Shigueno au Japon, et celui commercialisé par la Société Ralston Purina aux Etats-Unis. Bien qu'en particulier le taux de protéines de ces deux aliments soit sensiblement différent, et que les espèces faisant l'objet des tests soient elles-mêmes différentes (*P. japonicus* au Japon et *P. vannamei* aux Etats-Unis), les résultats expérimentaux sont assez voisins quant aux quantités journalières optima (2–4% du poids de l'animal par jour chez Shigueno et 3% pour Ralston Purina), ainsi qu'aux taux de conversion (entre 1.6 et 2.5 selon les autres conditions d'environnement) (Shigueno, 1975; Mountain, Persyn et Lawrence, non-publié).

L'importance de la disponibilité d'un aliment composé prend toute sa valeur lorsque l'élevage est tenté dans une zone géographique où la nourriture naturelle provenant de la mer fait défaut. En Polynésie, par exemple, où la production de mollusques ou de crustacés aptes à servir d'aliments est pratiquement nulle, l'équipe du Centre Océanologique du Pacifique doit pour le moment fabriquer elle-même ses aliments composés à partir des ressources locales. Les protéines nécessaires proviennent soit de farine de poisson, soit de feuilles d'acacia (*Leucaena leucocephala*). D'autres sources de protéines sont en voie d'expérimentation: aliments pour poulets, escargots (*Achatina fulica*), levures de pétrole, *etc.*

Les crevettes acceptent finalement des aliments bien dosés quelle que soit leur origine, à condition que leur conditionnement soit bien adapté. La forme la plus générale est celle de granulés à allure de vermicelle dont la stabilité dans l'eau doit être bonne et le caractère attirant se maintenir tout au long de l'élevage. L'un des problèmes est donc celui du 'liant' pour la détermination duquel un certain nombre d'expérimentations permettent désormais de faire un choix (Forster, 1972; Neal, 1973).

(ii) *Les facteurs d'environnement*

Si pour la commodité de l'analyse, on a séparé les facteurs nutritionnels des facteurs d'environnement, il est clair qu'il y a interaction des uns et des autres et qu'il est impossible de les isoler dans leurs effets.

Les qualités du milieu d'élevage nécessaires ou favorables sont actuellement assez bien connues pour l'essentiel. La température et la salinité dépendent bien sûr du choix du site, et sont optimales pour une température de 25–30°C, et une salinité voisine de 32–35‰. Le pH est un facteur important en particulier dans les zones conquises sur la mangrove où il est généralement bas. Des valeurs autour de 8 semblent les plus convenables. La hauteur d'eau est jugée satisfaisante entre 1 m et 1,50 m.

Les crevettes consomment relativement peu d'oxygène, mais la quantité d'oxygène dissous doit cependant être constamment surveillée par suite des consommations dues aux autres animaux existant dans les bassins, aux déchets de nourriture, aux déjections, aux algues et au sédiment lui-même. Des valeurs relatives de ces consommations ont été données par Shigueno, montrant dans un cas précis que le sédiment absorbait une quantité d'oxygène double de celle des crevettes en élevage (Shigueno, 1975). A Maguelone, en France, des mesures systématiques ont montré qu'en cours d'élevage l'évolution de l'oxygène dissous était moins liée aux variations de température et d'activité de la photosynthèse qu'aux conditions benthiques régnant dans le bassin, ces conditions procédant elles-mêmes des antécédents du bassin en tant que bassin d'élevage.

On notera en outre que le renouvellement d'eau, sauf à devenir considérable, ne peut avoir d'effet que plusieurs jours plus tard, lorsqu'un déséquilibre est franchi. Une solution à ce problème est le drainage du fond, qui sera examiné dans une section suivante. Mais la mise au point d'une sonde enregistreuse à oxygène dissous ou à sulfures dans le sédiment lui-même permettrait de déceler suffisamment tôt les tendances présentées par le bassin. Si la préparation du sédiment, après vidange du bassin, puis sa surveillance et son entretien ont fait l'objet d'observations et de recommandations, peu d'études ont été faites jusqu'ici sur l'effet relatif de différents types de sédiment, selon sa nature, son ancienneté géologique, sa granulométrie, sa compaction, sa porosité, sa couleur, *etc.*

Des expérimentations en laboratoire ont montré qu'une combinaison de basse température et de faible salinité avait un effet défavorable sur la croissance (Zein-Eldin et Griffith, 1969); des observations sur le terrain, à la station de Mana en Guyane, ont permis de vérifier que si les juvéniles croissaient correctement à faible salinité jusqu'à une taille voisine de 7 cm, un blocage de croissance survenait ensuite. Ces blocages de croissance ne dépendent pas que de la salinité. En particulier des phénomènes de ce genre, encore inexplorés, sont constatés en Polynésie dans des bassins dont le fond et les parois sont recouverts de feuilles plastiques.

Une remarque concerne précisément le rôle exact de la productivité naturelle dans les bassins d'élevage semi-intensif où l'essentiel de l'alimentation provient d'une nourriture distribuée. Il semble que ce point mériterait des éclaircissements qui ne peuvent encore être donnés. De la réponse dépend en particulier le choix d'un type de bassins permettant une fertilisation efficace.

(iii) *Résultats*

Une combinaison satisfaisante des différents facteurs examinés conduit en élevage semi-intensif à des rendements qui ne dépassent guère pour un cycle de production 300 g/m^2 d'eau. Des expériences menées tant au Japon qu' en France, il résulte d'ailleurs qu'il ne sert de rien d'augmenter la charge initiale c'est-à-dire le densité des post-larves. Il est maintenant généralement recommandé de procéder à un prégrossissement. La compagnie Ralston Purina aux Etats-Unis par exemple place les post-larves à P2–P3 dans des enceintes de prégrossissement à des densités allant jusqu'à 250 au m^2. Elles y restent deux mois et atteignent le poids moyen de 2 g. Par contre *dans la technologie actuelle* on ne saurait dépasser une charge initiale de 20–25 crevettes/m^2 si l'on veut que chacune d'entre elles atteigne la taille commerciale au bout de 4 mois d'élevage.

Cette limitation des rendements, jointe au coût élevé de la nourriture explique, compte tenu en particulier de la rareté et de la cherté des terrains disponibles, le piétinement du développement des élevages au Japon et les échecs dans les autres pays. D'où la nécessité de dépasser l'étape actuelle, soit en effectuant annuellement deux ou trois cycles d'élevage comme l'envisagent certains projets en Amérique Centrale (Webber, 1970), et plus généralement dans la zone tropicale, soit en modifiant partiellement ou totalement la technologie pour obtenir des rendements à l'unité de surface nettement supérieurs.

3.2.3 *Elevage intensif*

Les modifications partielles de la technologie sont pour le moment modestes. Elles visent en particulier de *drainage du sédiment.* Commencées en 1973 des expériences continuent tant au Centre Océanologique du Pacifique qu'en France dans des bassins à drainage inversé c'est-à-dire assurant une distribution de l'eau par les drains à travers le sédiment sus-jacent (L'Herroux, 1974).

Les tentatives les plus originales à l'heure actuelle sont d'une part les élevages en silos en cours de développement au Japon à Kagoshima sous la direction de Shigueno, d'autre part les élevages en 'raceways' étudiés au laboratoire de Galveston (Mock, Neal et Salser, 1973); les uns et les autres procèdent de l'idée qu'il faut réaliser un strict maintien de la qualité de l'eau et la faire circuler en abondance.

Dans les silos à double fond de la ferme expérimentale située près de la station de Kagoshima avec un renouvellement d'eau complet chaque jour et une nourriture composée—il a été obtenu une production supérieure à 2kg/m^2 (Shigueno, 1975).

Les essais pratiqués à Galveston ont montré la validité de raceways où la circulation de l'eau, l'aération et le nettoyage étaient accomplis par de simples systèmes d'air-lift. Si des gains de poids journaliers intéressants ont été constatés à une charge au m^2 très importante, le grossissement n'a pas été conduit jusqu'à la taille commerciale.

3.2.4 *Perspectives*
Pour un certain temps encore l'élevage semi-intensif dans des enceintes aménagées ne dépassant pas quelques hectares est celui dont le développement est le plus probable, mais à condition qu'une nourriture composée puisse être fournie à un prix abordable. Une meilleure connaissance des conditions d'environnement permettra sans doute d'augmenter légèrement les rendements tandis que la maîtrise de la maturation et de la ponte conduira à organiser deux cycles de grossissement par an chaque fois que les conditions climatologiques le permettront. Mais dans un avenir plus ou moins proche, et dans les pays développés, il est certain que s'imposeront progressivement des élevages entièrement contrôlés à très haut rendement.

3.3 *Grossissement des crevettes d'eau douce*—Macrobrachium rosenbergii
Le grossissement des crevettes d'eau douce a été réalisé ces dernières années au niveau d'installations pilotes de caractère semi-intensif d'abord à Hawaï (Fujimura et Okamoto, 1972), puis notamment à l'Ile Maurice, à Tahiti et aux Etats-Unis en Caroline du Sud avec des résultats concordants.

On peut synthétiser ces résultats de la façon suivante: (*a*) nécessité d'un prégrossissement d'un ou deux mois, (*b*) mise en élevage à la densité de 10–30 individus/m^2 dans des bassins en terre alimentés en eau de bonne qualité, (*c*) température optimum voisine de 25°C, température léthale voisine de 16°C, (*d*) aliment composé sans grandes exigences, (*e*) nécessité absolue de zones d'ombre et d'abris (jacinthes d'eau), (*f*) hétérogénéité de la croissance.

Dans ces conditions on peut espérer, avec une durée d'élevage de la larve jusqu'à la taille commerciale d'environ onze mois, un rendement de l'ordre de 3–4 tonnes/ha. C'est le résultat obtenu par la première installation d'Ota's Ponds à Hawaï démarrée en 1971 sur 0,7 ha environ.

A Tahiti (Centre Océanologique du Pacifique) plusieurs centaines de kilogrammes ont déjà été produites et commercialisées dans les conditions suivantes: prégrossissement en bassins circulaires de 12 m^3 à la densité de 160 individus/m^2, grossissement sur une nourriture à base de tourteaux de coprah, de drèches de brasserie et de feuilles d'acacia—survie moyenne supérieure à 50%, rendement extrapolé de 2 à 3 tonnes/ha.

Aux Etats-Unis des résultats comparables ont été obtenus au Marine Resources Research Institute de Charleston (Sandifer et Smith, 1975).

Cependant à notre connaissance, et en dehors peut-être des installations de Kenneth Kato's Fish Farms de Pacific Aquaculture à Hawaï, aucune ferme de taille commerciale ne fonctionne encore en routine avec des résultats bénéficiaires. De nombreux projets sont par contre sur le point de démarrer. Citons en particulier celui de Caribe King Shrimp, Inc. à Porto Rico où 36 bassins d'un demi-hectare commenceraient leur production.

Par contre, des essais d'*élevage intensif*, sous contrôle total, visant des productions allant jusqu'à 70 tonnes/ha/an sont entrepris par des chercheurs ayant leur propre société (Grajcer à Menlo Park près de San Francisco; Serfling en Californie).

Un développement de l'élevage de la crevette d'eau douce est cependant à prévoir. Il sera limité par la disponibilité d'une eau de qualité à des températures suffisantes, et par la durée de l'élevage, mais se technologie relativement simple doit lui conférer vite un caractère de grande fiabilité.

4 Les problèmes pathologiques

Les maladies sont l'un des plus importants facteurs susceptibles de contrecarrer le développement d'un élevage. Sans doute exercent-elles leurs effets dans le milieu naturel, mais ceux-ci sont cependant très aggravés en élevage par suite des hautes densités et du confinement des animaux. De grands progrès ont été faits ces dernières années pour identifier les maladies des crevettes et mettre au point les mesures préventives ou curatives les plus appropriées. Citons d'abord l'effort de classification entrepris par Johnson (1975) pour ce qui concerne trois espèces de pénaeides.

4.1 *Pathologie des élevages larvaires*
Aux premiers stades de développement, c'est-à-dire de l'œuf jusqu'à la 'mysis', l'attaque la plus redoutable paraît être celle d'un champignon du genre *Lagedinium* dont la prolifération entraîne des mortalités massives. Ces attaques ont été constatées sur trois espèces de pénaeides à Tahiti (Aquacop, 1975) et sur plusieurs autres aux Etats-Unis et au Mexique (Umphlett et McCray, 1975).

Des essais de traitement sont actuellement en cours avec du Treflan et du vert malachite avec apparemment des résultats satisfaisants.

Aux stades suivants, de la mysis à la post-larve, les animaux peuvent faire l'objet d'atteintes de *Vibrio* qui provoquent des mortalités allant dans certains cas jusqu'à 100%. C'est ainsi qu'après la mise en évidence depuis plusieurs années de *Vibrio* spp. sur *Penaeus japonicus* deux autres espèces ont été isolées aux Etats-Unis sur des larves moribondes de *P. setiferus* et *P. aztecus* (Lightner et Lewis, 1975). Les traitements aux antibiotiques sont efficaces s'ils sont effectués à temps.

4.2 *Pathologie du grossissement*
On peut distinguer ici d'une part les atteintes bactériologiques, d'autre part l'infestation par parasites, enfin l'effet de facteurs d'environnement. Les atteintes bactériologiques ne paraissent pas encore complètement identifiées quant à leurs agents.

Notons la 'maladie des points noirs' caractérisée par l'apparition de tâches noirâtres à différents endroits de la crevette avec décoloration des bords latéraux de la carapace abdominale. Cette maladie, constatée sur *P. japonicus* par Shigueno (1975) et attribuée à un *Vibrio*, a été observée à Tahiti sur *P. aztecus*.

Mieux connue ou plus largement observée est la maladie des branchies constatée au Japon sur *P. japonicus* et plusieurs fois notée sur la même espèce dans les élevages expérimentaux de Maguelone en France, maladie qui se traduit par le noircissement des branchies et l'affaiblissement général des animaux. L'étude bactériologique a abouti à l'isolement de plusieurs espèces de bactéries non pathogènes vis-à-vis de l'animal sain. Ceci sous-tend une observation plus générale selon laquelle nombre de maladies ne sont en fait que des manifestations secondaires d'effets d'une mauvaise alimentation ou de la mauvaise conduite des bassins.

Les parasites des crevettes pénaeides ont fait l'objet d'études particulières (Overstreet, 1973) sans qu'un lien direct ait pu être établi jusqu'ici avec un affaiblissement grave des sujets.

En ce qui concerne les facteurs d'environnement l'attention est attirée sur la possibilité de voir contracter la 'gas bubble disease' par les juvéniles de pénaeides à la suite d'une sursaturation résultant d'un chauffage de l'eau avec augmentation de pression (Lightner, Salser et Wheeler, 1974).

4.3 *Perspectives*

A l'heure actuelle, les problèmes pathologiques principaux concernent les élevages larvaires, pour lesquels des mortalités massives sont encore constatées sans possibilités pratiques d'intervention. Aussi un effort accru doit-il être appliqué à la compréhension des phénomènes et à la définition des *mesures préventives* indispensables. Le travail est à peine commencé en ce qui concerne *M. rosenbergii.*

Jusqu'à plus ample informé, les maladies au cours du grossissement, en élevage semi-intensif, sont la plupart du temps des phénomènes secondaires, susceptibles d'ailleurs dans certains cas d'être efficacement traitées.

Il n'en sera pas de même avec les élevages intensifs du proche futur où les atteintes épidémiologiques risquent d'être beaucoup plus dangereuses. Aussi est-il souhaitable que ce sujet retienne l'attention des spécialistes et qu'une coopération étroite permette à tous de disposer de l'ensemble des observations et résultats d'expérimentations disponibles.

5 Les problèmes technologiques

La plupart des problèmes technologiques ont déjà été évoqués, sinon traités, dans les sections précédentes car ils sont dans une large mesure inséparables des problèmes biologiques. Il n'en reste pas moins que dans bien des cas des solutions alternatives peuvent être prises en considération et qu'il est du plus grand intérêt de les examiner avec le plus grand soin car de leur choix dépend non seulement la réussite physique de l'élevage mais aussi le poids relatif et global des coûts d'investissement et de fonctionnement. On ne leur donnera cependant, ci-dessous, qu'un développement limité, compte tenu du fait qu'ils n'ont pas sensiblement évolué depuis plusieurs années.

5.1 *Choix d'un site*

(i) *Crevettes de mer*

Si l'on se place en dehors du cas de l'élevage intensif où, à la limite, toutes les conditions nécessaires peuvent être créées artificiellement, il est clair que les deux facteurs nécessaires, mais non suffisants, pour apprécier la capacité d'une région côtière à soutenir des élevages de pénaeides sont *la température* et *la salinité* de l'eau de mer. Si la température ne se maintient pas au-dessus de 25°C pendant au moins quatre mois consécutifs, si la salinité descend durablement en dessous de 30‰, il est impensable d'envisager un élevage. Mais si ces conditions primordiales sont réunies, encore en faut-il un certain nombre d'autres.

Tout d'abord l'expérience des dernières années a montré que nous n'étions pas prêts à mettre en culture des portions importantes de milieu naturel quel que soit le type d'enclos utilisé. L'état de la technologie actuelle ne permet guère d'envisager en semi-intensif que des bassins de superficie inférieure à 10 ha et probablement même à 5 ha. L'élevage se faisant sous faible hauteur d'eau et nécessitant un sédiment de bonne qualité, ceci privilégie les côtes alluviales et lagunaires dont au surplus la productivité naturelle est en général élevée. La capacité de disposer d'un aliment naturel en grandes quantités, à proximité immédiate, est un autre facteur de choix.

(ii) *Crevettes d'eau douce*

La température, la qualité et le débit d'eau douce disponible conditionnent l'élevage. Le choix s'opère ensuite suivant les facilités de construction et de maintenance des bassins, la proximité d'une écloserie (située sur la rive) et des sources d'aliments.

Dans les deux cas, on ne saurait oublier, bien sûr, la distance au point de commercialisation, la nature et le coût des moyens de transport et de conditionnement.

5.2 *Différents types d'enceintes*

(i) *Crevettes de mer*

Les enceintes les plus utilisées sont les bassins à fond de terre ou de sable non drainé, avec digues en terre. Alimentés par le jeu des marées ou par pompage, le renouvellement de l'eau reste assez faible de l'ordre de 1/5 ème du volume total par jour. Le pompage, plus coûteux, permet un bien meilleur contrôle des périodes de renouvellement d'eau, et surtout de l'entrée des prédateurs. Les meilleurs bassins sont ceux qui se vident entièrement, permettant ainsi, outre une pêche facile, le nettoyage et l'entretien périodiques de sédiment et la fertilisation. Ces types de bassins sont ceux des fermes japonaises actuelles en exploitation commerciale. Les rendements qui y sont obtenus sont de l'ordre de 2 à 3 tonnes/ha/an.

Pour augmenter les rendements, il faut conjointement augmenter le renouvellement d'eau (donc procéder par pompage — ou bassin réservoir), et utiliser des fonds drainés. Les systèmes utilisés en France à titre expérimental ont des drainages inversés c'est-à-dire que l'eau circule de bas en haut à travers le sédiment ce qui présente l'avantage de garder un sédiment meuble et toujours bien oxygéné. Mais il ne s'agit encore que d'installations pilotes de quelques ares.

L'utilisation d'enclos en filets, au lieu de digues, pose deux problèmes: le contrôle des prédateurs dont les alevins peuvent pénétrer à traverse les mailles, et la salissure du filet. S'il n'y a pas de remède au premier, on peut régler le second de façon satisfaisante par des dispositifs permettant de changer les filets (double rangée de supports de filets— par exemple).

L'élevage en cages qui se pratique avec un si grand succès pour les poissons, et présente d'incontestables avantages puisqu'il ne nécessite pas de pompage et permet une évacuation naturelle des déchets, est une voie d'avenir intéressante. Elle est actuellement testée au Japon sur *P. japonicus* avec au fond de la cage un fond artificiel remplaçant le sédiment. Cette technique, qui rendrait de nombreux sites propices à l'élevage, conviendrait mieux aux espèces qui s'enfouissent peu comme *P. merguiensis.*

Enfin rappelons les essais d'élevage intensif en silos de Shigueno, et en raceways de l'équipe de Galveston avec utilisation ou non de circuits fermés, qui visent à atteindre de très hauts rendements dans des conditions de contrôle accrues.

(ii) *Crevettes d'eau douce*

A notre connaissance les enceintes utilisées pour l'élevage de *M. rosenbergii* sont jusqu'ici des bassins en terre aménagés en dérivation le long d'un cours d'eau. Le nombre

d'élevages est encore insuffisant pour que des diversifications de quelque intérêt aient pu être testées. La forme rectangulaire est généralement adoptée.

5.3 *Méthodes de récolte*

La récolte ne pose des problèmes que dans les bassins qui ne peuvent être vidés complètement. Dans ce cas la capture par filet piège, ou la pêche au petit chalut électrique, ont donné de très bons résultats. Dans les bassins qui se vident, il suffit de placer une grande poche de filet à la sortie de l'évacuation.

6 Conclusion

Malgré les efforts déployés pour le progrès des techniques, d'abord au Japon, puis en Angleterre, aux Etats-Unis et en France, l'élevage des crevettes de mer en est encore au stade de l'enfance. En dehors de l'élevage extensif de la zone indo-pacifique, des élevages commerciaux à rendement moyen n'existent en fait qu'au Japon où depuis dix ans leur production globale s'est stabilisée entre 200 et 800 tonnes/an. Les élevages tentés aux Etats-Unis ont échoué; ceux envisagés en Amérique Centrale n'ont pas encore fait leurs preuves; la France n'a volontairement pas dépassé le stade de l'installation pilote tant qu'une hypothèque fondamentale, celle de la maturation et de la ponte de géniteurs captifs n'était pas levée. Ce premier verrou de l'élevage est en voie d'être ôté. D'ici peu de temps on pourra donc envisager la culture de crevettes pénaeides en dehors de leurs aires de distribution naturelle, sous des conditions climatiques favorables au grossissement. Parallèlement les efforts faits sur la mise au point d'une nourriture artificielle ont maintenant abouti à plusieurs formules satisfaisantes. Néanmoins, le piétinement de l'aquaculture de la crevette au Japon, où le problème de l'approvisionnement en juvéniles ne se pose pas, montre qu'il reste à surmonter d'autres obstacles, de nature essentiellement économique. Dans ce pays, où le prix de vente sur le marché de la crevette vivante est le plus élevé du monde, les coûts d'investissement (terrain) et de fonctionnement (aliment) pèsent encore trop lourd pour les rendements atteints, et sollicitent donc un nouveau progrès technologique.

On voit ainsi se dessiner logiquement deux orientations principales pour l'avenir. Dans les pays tempérés, où l'élevage n'est possible à l'extérieur qu'à la saison chaude, les techniques doivent encore faire un pas de plus vers des rendements accrus, avec une fiabilité quasi-totale. Dans les pays tropicaux, où la main-d'œuvre très qualifiée ne sera que progressivement disponible, c'est la possibilité d'un élevage continu avec deux récoltes par an au moyen d'une technologie simple, qui va retenir l'attention.

Il est enfin vraisemblable qu'avec la possibilité de commencer des travaux de génétique, la sélection, et plus tard l'hybridation, feront sentir leurs effets bénéfiques tant au plan de l'aptitude à l'élevage qu'à celui de la résistance aux maladies.

Ce qui est en tous cas certain, même si la date ne peut en être précisée, c'est qu'avec le développement de la population mondiale et la diversification de son alimentation, la crevette d'élevage prendra progressivement le relais de la crevette sauvage dans une croissance générale des produits d'aquaculture. Un bel avenir aussi attend l'élevage de la crevette d'eau douce, dont à certains égards la technique est plus simple, mais pour laquelle les conditions favorables climatiques et géographiques sont en première évaluation, moins largement réparties.

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Recent Progress in the Farming of Kuruma Shrimp (*Penaeus japonicus*)

H. Kurata and K. Shigueno

Abstract
Progress in development of kuruma shrimp (*Penaeus japonicus*) fry production techniques and pond culture methods since the inception of shrimp farming in 1933 are reviewed, as well as the technical advances achieved in shrimp stocking techniques.

The first steps toward mass production of shrimp fry were simple—largely supported by experience and intuition; these were followed by development of the community culture method in which an adequate concentration of shrimp larvae and food organisms were maintained by the addition of nutrients. The next development, just coming into practice, is the establishment of an automatic rearing system in which feeding and physico-chemical conditions are carefully controlled.

Pond culture of shrimp for consumption has expanded significantly over the last decade, and in 1974 there were almost 50 shrimp culture enterprises in Japan farming an area of 245 ha and producing almost 600 tons of live shrimp. Considerable effort has been devoted recently to development of a suitable compounded feed to substitute for the fresh short-necked clams and blue mussels previously used as feed and in developing a new culture method in a controlled environment.

There is general agreement in Japan that liberation of sedentary fry of kuruma shrimp not only has the potential of increasing local shrimp production, but could also support a considerable fishery if adequate quantities of fry are released. Effective techniques related to this method of shrimp farming have been developed, and efforts should now be made to improve the economic feasibility and cost-benefit of this practice.

Progrès récents de l'élevage de la crevette kuruma (*Penaeus japonicus*)
Résumé
On fait le point des progrès accomplis dans le développement des techniques de production et les méthodes d'élevage en étang de juvéniles de crevettes kuruma (*Penaeus japonicus*) depuis les débuts de l'élevage de la crevette en 1933, ainsi que des perfectionnements des techniques de peuplement.

Les premières étapes de la production en masse de juvéniles de crevettes ont été simples et se sont fondées en partie sur l'expérience et l'intuition; on a ensuite mis au point la méthode de culture en communautés, qui consiste à maintenir une concentration adéquate de larves de crevettes et d'organismes alimentaires grâce à l'adjonction d'éléments nutritifs. L'innovation suivante, dont l'application pratique commence à peine, consiste en l'installation d'un système d'élevage automatique dans lequel les conditions de nourrissage et les conditions physicochimiques sont minutieusement contrôlées.

L'élevage de la crevette dans des étangs, aux fins de la consommation, s'est beaucoup développé au cours de la dernière décennie. En 1974 au Japon il existait presque 50 entreprises d'élevage de la crevette, exploitant une superficie de 245 ha et produisant un total voisin de 600 tonnes de crevettes vivantes. On a récemment déployé des efforts considérables pour mettre au point un aliment composé convenable destiné à remplacer les moules communes et 'short-necked' clams frais précédemment utilisés pour le nourrissage, ainsi que pour élaborer une nouvelle méthode d'élevage dans un milieu contrôlé.

Au Japon, on s'accorde à reconnaître que la libération de juvéniles sédentaires de crevettes kuruma permettrait non seulement d'accroître la production locale de crevettes, mais aussi peut-être d'entretenir une pêcherie d'une importance considérable si l'on relâche des quantités suffisantes de juvéniles. Des techniques efficaces ont été mises au point en rapport avec cette méthode d'élevage de la crevette et il faudrait maintenant s'efforcer d'améliorer la faisabilité économique et le rapport coûts-bénéfices du système.

Progresos recientes en la cría del camarón kuruma (*Penaeus japonicus*)
Extracto
Se examinan el desarrollo de los progresos realizados en las técnicas de producción de formas juveniles del camarón Kuruma (*Penaeus japonicus*) y los métodos de cultivo en estanque desde que comenzó la cría de camarones en 1933, y se indican los progresos de las técnicas de siembra de camarones.

Los primeros pasos para la producción masiva de camarones jóvenes se dieron sencillamente, basándose sobre todo en la experiencia y en la intuición; se introdujo luego el método de cultivo colectivo, en el que, mediante la adición de nutrientes, se mantiene una concentración adecuada de larvas de camarones y organismos para alimentarlos. El paso siguiente, que está dándose ahora, consiste en el establecimiento de un sistema automático de cría, con condiciones de alimentación y fisicoquímicas atentamente controladas.

El cultivo de camarones en estanques para consumo ha aumentado notablemente durante el último decenio. En 1974 en el Japón existían casi 50 empresas dedicadas a ese cultivo que explotaban una superficie de 245 ha y producían casi 600 toneladas de camarones vivos. Recientemente se han hecho esfuerzos considerables para conseguir un nuevo pienso compuesto que sustituya a las almejas de sifón corto y los mejillones azules utilizados anteriormente como alimento y preparar un nuevo método para cultivar camarones en un ambiente controlado.

Todos coinciden, en el Japón, en que la suelta de formas juveniles sedentarias de camarón Kuruma no sólo permite aumentar la producción local de camarones sino que, además, si se hiciera en cantidades suficientes, podría sostener una pesquería considerable. Se han preparado técnicas eficaces para promover este método de cría de camarones. Ahora es necesario mejorar la viabilidad económica y la relación costos-beneficios de esta práctica

1 Introduction

Surrounded by a large expanse of temperate fertile seas—at the meeting place of the warm water from the south and the cold water from the north—the Japanese people have cultivated a particular preference for sea foods. A great variety of fish and shellfish are served raw, the delicacy of their natural flavour is highly appreciated, and it is the 'live' commodities which are most esteemed and obtain the highest price in the market. It is almost impossible in fact, to understand the rationale underlying the expectation and significance associated with the kuruma shrimp culture industry in Japan without referring to this special food preference, the manner in which fishery products are brought to market, and the increasing demand for luxury sea foods.

Kuruma shrimp (*Penaeus japonicus*) is a warmwater species widely ranging over the Indo-West Pacific region. During the winter months when shrimp catches in the

capture fisheries are minimal, the demand is highest, and the selling price to the producer of live kuruma shrimp may be as high as US$ 35/kg in the Tokyo market. A variety of penaeid shrimps, imported from various parts of the world, are sold frozen or half-cooked for consumption in ordinary restaurants and for home cooking, but these do not compete with the live kuruma shrimp which are used exclusively in first-class restaurants as a luxury food.

This report will briefly summarize the present state of the techniques involved in (*i*) the production of fry, (*ii*) their growth in ponds, (*iii*) their processing, shipping, distribution and marketing and, finally, (*iv*) the prospects of stocking and farming them at sea.

As minimal background for this description it may be noted that the farming of penaeid shrimp has long been practised in tropical waters of the Indo-West Pacific area. It was, however, dependent upon the use of natural seedlings and natural foods, and it was not until artificial culture was initiated in Japan in 1933 by Dr. M. Fujinaga, followed by many years of trial and error, that it developed into an industry (see Fujinaga's publication under the name of Hudinaga, 1942). Among the principal steps in this development were: (*i*) the discovery that mature females may lay their eggs when placed in aquaria, (*ii*) the discovery that adequate light intensity is necessary for successful rearing, (*iii*) use of large outside tanks in which the shrimp and their suitable food organisms are kept together under proper management of light intensity, aeration, and concentration of nutrients ('community culture'), (*iv*) the substitution of *Chaetoceros* sp. for *Skeletonema* sp. as a food, and (*v*) chemical sterilization of tank water.

Mass production of seedlings in Japan now amounts to almost 200 million individuals and industrial production of marketable shrimp amounts to 600 tons. Furthermore, techniques for artificial production of shrimp seedlings have been developed not only for the kuruma shrimp, but also for other penaeid shrimps throughout the world.

In 1968 a new concept was developed which aimed at the practical improvement of shrimp yields through stocking large numbers of hatchery-reared fry in the shallow seas; section 4 will be devoted to this challenging approach.

2 Production of fry (seedlings)

2.1 *Breeding tank*

Neither the size nor shape of a breeding tank has a particular effect upon the results. Generally speaking, however, a greater number of fry per unit volume of water is produced in a small tank. In Japan, concrete tanks of about 10 m × 10 m × 2 m deep are commonly used for mass production. They have inflow, outflow, aerating and heating systems, and, sometimes, rotary agitating devices are installed. Optimum aeration is about 0·04 m^3 per m^2 of tank bottom.

2.2 *Rearing water*

The water used for rearing kuruma shrimp fry is natural sea water filtered through 100–150 mesh netting which removes debris and large plankters, and yet allows diatoms to pass. Turbid water is avoided or filtered through sand layers.

When spawners are first introduced the tank is filled to only about one-half or one-third of its capacity. After the larvae have attained the mysid stage, fresh sea water is gradually added. By the time the shrimp have reached their early postlarval stage the water will be almost full depth, and must be renewed by 20–40% of its volume each day—depending on the degree of accumulation of metabolites and food residues.

2.3 *Spawners and success of spawning*

Spawners, obtained from commercial catches, are shipped to the hatchery and put in the spawning tank as soon as possible. Mere transfer into the tank water is usually enough to induce spawning.

The degree of ripeness of the spawners, as seen through the dorsal integument, is recognized by the size and colour of the ovaries. About 50% of the ripe females will spawn successfully on the first or second night after stocking. Small females usually spawn more successfully than larger ones.

2.4 *Hatching*

About one-half of the fertilized eggs will hatch into nauplii within 14–15 hours after spawning. The number of nauplii obtained depends on the size of the spawning female; it usually averages 200 000 per female in mass production practices.

2.5 *Larval development*

The period required from spawning to metamorphosis is about 10 days, and from metamorphosis to the attainment of seedling-size is about 20 days under standard conditions. A longer period may be required under unfavourable conditions such as low temperature, overcrowding or food shortage. The standard size of a kuruma shrimp seedling (postlarva) is about 10 mm in body length or 0·01 g wet weight.

The benthic habit appears in the postlarvae after 3–4 moults and attainment of 6–7 mm in body length. They then begin to cling to the walls and bottom of the tank. In nature, however, the postlarvae are believed to acquire benthic existence toward the end of stage 2.

2.6 *Food and feeding*

The nauplius grows on its own yolk but, after attaining the protozoeal stage, the larva must be fed.

The basic foods commonly used for protozoea are planktonic diatoms such as *Skeletonema costatum* and *Chaetoceros* sp. These are cultured in the rearing tank together with the shrimp larvae by adding nutrient salts. The optimal concentration of food diatoms is 1 000–3 000 cells per ml of rearing water.

The mysids and early postlarva are usually fed brine shrimp (*Artemia salina*) nauplii. They consume about 50 and 80–100 nauplii a day respectively. The later postlarva is fed minced clams or mussels. Its standard daily ration is 2–3 times its body weight, but in practice the ration is regulated according to feeding activity.

There are various substitutes for these larval foods. The eggs and trochophore larvae of oyster may be used successfully for protozoea, diatoms and rotifers for mysids, rotifers and copepods for the early postlarvae, and copepods, polychaetes, small shrimps and compounded diets for the later postlarvae.

2.7 *Stocking density and survival rate*

In mass production of fry the standard stocking density of newly hatched nauplii is about 50 000 per m^3 of tank

capacity. In order to yield this density at least one spawning female, or two ripe females when the rate of spawning success is taken into consideration, will be required for every 4 m^3 of tank capacity.

The survival rate from the newly hatched nauplius to metamorphosis averages 60–70%. During the postlarval stages the survival rate is distinctly density-dependant and commonly lies between 30 and 60%. Thus the average overall survival rate from newly hatched nauplius to postlarva of seedling size is 20–30%.

2.8 *Harvesting, counting and shipping*

When harvested, the seedlings are concentrated by draining the tank to one-half or one-third its depth. They are then attracted by light and scooped out with a hand net at night, or are flushed through the outlet with the rearing water to be netted.

The number of seedlings is usually calculated by dividing the total wet weight by the average weight of an individual. The latter figure is obtained by weighing a known number of seedlings.

As many as 700 000 seedlings may be shipped by truck for up to about 12 hours in a plastic container of one-ton capacity equipped with an aeration system.

2.9 *Efficiency of production*

The efficiency of production may be expressed by several parameters. Generally speaking, their average values in routine mass production practice are considerably lower than the best values obained in experiments in which the rearing conditions have been much more carefully controlled.

The first parameter is the number of seedlings produced per m^3 of tank capacity per cycle: the average value is usually 10 000–15 000. The second is the number of seedlings produced per spawning female: the average value is 20 000–30 000. The third is the production cost. Table I provides information on production costs in 1967 in a shrimp hatchery where about 4 million seedlings had been produced during the summer. The cost per seedling of the P_{20} stage was about Yen 0·37, of which about 27% is accounted for by depreciation of the rearing tanks and 20% by wages.

TABLE I
COST IN 1967 OF PRODUCING 4 MILLION KURUMA SHRIMP SEEDLINGS OF P_{20} STAGE DURING THE SUMMER[1]

Items	*Amount (kg)*	*Value (Yen '000)*
Gravid females	50	150
Brine shrimp eggs	36	160
Clam with shell	3 000	195
Chemicals		50
Tools and expendable goods		150
Power		80
Wages		300
Depreciation of tank		400
Total		1 485

[1] Modified from Shigueno (1975)

2.10 *Development of new methods*

Since 1969, unexpected mass mortalities of mysids and early postlarvae due to disease have been reported with increasing frequency in many hatcheries. The mechanisms underlying these failures are poorly understood, but inability to achieve control of rearing conditions such as water quality and the community of micro-organisms in the rearing water seems to be primarily responsible. This situation has forced re-examination of the community culture principle and the development of a new method.

Promising results have been obtained by scientists at the Kagoshima Fisheries Research Station. The rearing water has been prepared by filtering sea water through sand layers, sterilizing it with sodium hypochlorite (150 ppm) and neutralizing it 12 hours later with sodium thiosulphate (45 g/m^3). The protozoea and mysids have been fed a pure culture of *Chaetoceras* sp. instead of mixed plankton. Several kinds of compounded feed have also been developed by Deshimaru and Shigueno (1972) for the postlarvae.

It has been demonstrated that by use of this method, the rearing water can be maintained in good quality throughout the growing period without any trouble from disease—at least, to date.

3 Growing shrimp in ponds

3.1 *Construction and preparation of ponds*

The general layout of the shrimp ponds in Japan is shown in Fig. 1. Exchange of pond water is effected by the rise and fall of the tides through a water gate installed in each pond. The water gate opening inside is surrounded by a screen fence to prevent the intrusion of predatory fish. The bottom is generally flat and levelled to hold 1–1·5 m of water, with several slanting shallow trenches running from the periphery toward the water gate to facilitate drainage.

Prior to stocking fry, the pond water is completely drained and the substrate ploughed repeatedly, so that predatory fish can be eliminated and the bottom sand exposed to the sun to accelerate oxidation. Within about ten days, after less than 70 cm of water is let into the pond, communities of diatoms and an associated fauna of small animals, which constitute important items of natural food for shrimp fry, will swarm and the pond is now ready to receive shrimp fry.

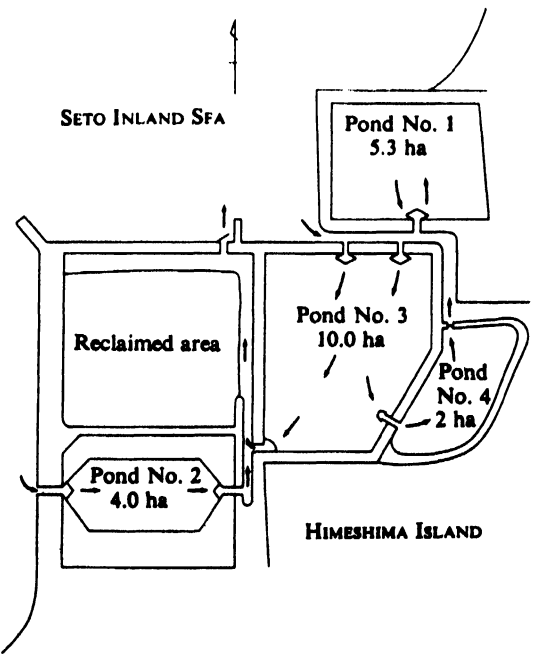


Fig 1. Layout of typical Japanese shrimp ponds at Himeshima Shrimp Farm Co

3.2 *Significance of the nursery pond*

During the early stages of culture practice, seedling shrimp fry (P_{20}) were released directly over the whole area of the growing pond. However, it soon became apparent that eggs and larvae of various predatory fish entered the pond through the screen in the water gate. They grew rapidly, snatching the food given to the shrimp and, in about three months, were big enough to prey upon the shrimp. As a consequence of such competition and predation, feed was wasted and a high proportion of the shrimp were lost. In addition, overwhelming swarming and subsequent decomposition of the green algae, *Ulva*, frequently occurred, resulting in pollution of the pond water and consequent suspension of shrimp growth. It was realised that for better shrimp growth, the pond operation period should be as short as possible.

To overcome such difficulties the culture operation is now divided into two successive processes: nursing and growing. One of the shrimp ponds may be used as a nursery where the fry are kept for about 50 days, until they attain an average body weight of about 1·5 g. They are then captured at night by a pound net and their number calculated by weighing them. They are then transferred to a well prepared growing pond to be cultured to marketable size. The nursery pond, when it has completed its function, is also used to grow another batch of early adolescent shrimp. The whole process of shrimp culture as practised at Himeshima is illustrated in Fig. 2.

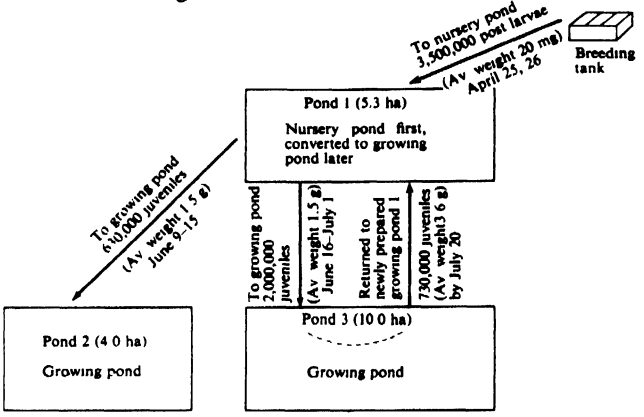


Fig 2. Diagram showing the process of shrimp culture from larval breeding to the attainment of marketable size, adopted at Himeshima in 1971

During the early stage, the shrimp in the nursery pond are fed with minced clam meat 2–3 times daily, but feeding is reduced to once a day at later stages. The survival rate of shrimp from stocking until the end of the nursery stage is about 70% and from transfer until harvest 95% or higher.

3.3 *Growing shrimp to marketable size*

Experience has shown that the fresh meat of short-necked clams and blue mussels are excellent feeds for growing shrimp in ponds. These feeds cannot be substituted with frozen fish or shellfish, especially during summer. However, there are several problems to be considered. When shelled by hand, the clam meat which is obtained amounts to almost 20% of gross weight; when crushed with a hammer-mill, as is usually practised by shrimp culturists, the yield is only about 11%. In the Seto Inland Sea the cost of clam with shell was US$ 0·02/kg in 1963, but the price rose rapidly, and by 1975 was US$ 0·09/kg. In addition, in recent years the supply has been insufficient to satisfy demand.

Another problem, inherent in the use of clam meat, is the unfavourable effect of shells left on the bottom, converting the bed into a hard and rough surface which prevents burrowing by the shrimp.

The results of growing shrimp in the three ponds at Himeshima (see Figs. 1 and 2) are summarized at the bottom of this page.

Pond No. 3 gave poor results in respect to growth, survival and feeding quotient (kg of food used to produce 1 kg of shrimp) compared to that in the other two ponds. The reason was attributed to its filthy bottom soil and limited water circulation. The feeding quotient varied considerably, ranging from 5·7 to 19·7. The conversion ratio depends on the degree of success in feeding management, quality of food given, and amount of natural food available in the growing pond. Generally speaking, the conversion of food into shrimp meat is less efficient in older than in younger shrimp (Fig. 3).

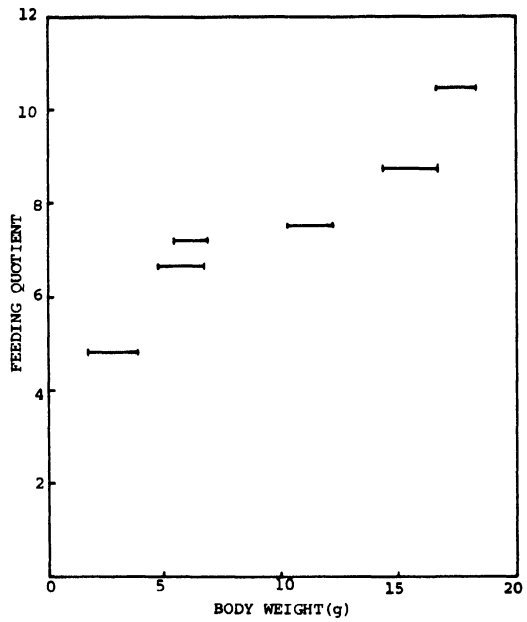


Fig 3. Variation of the feeding quotient with the weight of shrimp cultured with clam meat as food

The survival rates during the growing period are usually higher than 80% if large fry (1·1–6·0 g) are released, but stocking of small fry (0·05 g each) usually results in survival rates of 65-70%, or as low as 31% in a six-month period. Strictly speaking, survival does not depend solely on the size of fry but also on proper management of the culture, including predator eradication, maintenance of a

Pond No.	*No. stocked*	*Harvest*		*Av. wt (g)*	*Food tons*	*Feeding quotient*
		No.	*tons*			
1	730 000	788 400	14·08	17·8	93·54	6·6
2	630 000	636 300	11·43	17·9	68·61	6·0
3	1 050 000	997 500	14·03	14·1	137·80	9·8

balanced ecosystem and adequate quantitative and qualitative feeding.

In shrimp ponds, such as those popular in the Seto Inland Sea, the maximum rate for stocking fry is limited to 20/m^2. Higher stocking rates will lower the average shrimp weight below the profitable market size of 20–25 g. In other words, the maximum shrimp production in this type of pond culture will be limited to 250 g/m^2/year.

3.4 *Pond management*

3.4.1 *Control of predatory fish.* Many predatory fish such as the seabream (*Sparus major* and *Acanthopagrus schlegelii*) and the goby (*Tridnetiger obscurus*) spawn in April-May when shrimp fry are just released, and great numbers of their eggs and larvae enter the shrimp pond through the screen. They grow rapidly there and attack the shrimp. Usually, predation attains considerable intensity when shrimp are cultured throughout from P_{20} fry. Predation and competition for food may be minimized by adopting the nursery process. Treatment of pond water by rotenone in derris root, or saponin in tea seed cake will eliminate predators.

3.4.2 *Water circulation.* The exchange of pond water is minimal during neap tides in summer, as it depends only on the daily tidal rise and fall. In spite of every effort to maximize the water circulation, it tends to be inadequate, and a rise of temperature, accompanied by lack of dissolved oxygen on hot windless days, may result in mass shrimp mortalities. The phytoplankton bloom produces enough oxygen during the daytime to consume ammonia and carbon dioxide. However, once this activity is impaired, oxygen production does not satisfy demand and the oxygen level may be lowered below the lethal threshold. From a study of oxygen consumption in a 35 000 m^2 shrimp pond at Aio, Shigueno (1975) estimated that the shrimp took only 8·6% of the total consumption of 105 × 10^6 ml oxygen during 12 h at night, as shown below.

Oxygen consumer	*Amount of O_2 consumed (ml)*	*Percentage*
Kuruma shrimp	9 072 000	8·6
Other shrimp	592 200	0·5
Fish	7 106 400	6·7
Bottom sand	15 540 000	14·8
Water	—	69·4

By far the greater fraction was consumed by the pond water containing micro-organisms and suspended organics.

3.4.3 *Bottom soil.* In the course of time the pond bottom becomes polluted by chemical reduction, due to the accumulation and decomposition of organic matter, including unconsumed food materials, metabolites and dead organisms, leading to a serious retardation in shrimp growth. The interstitial waters of bottom sands are almost completely deprived of dissolved oxygen and may instead contain 5–7 ppm of hydrogen sulphide which, if it comes into contact with shrimp, is enough to cause instant death. Under such conditions the shrimp tend to stay on the bottom even in daytime, but in the evening they swim on the surface and frequently jump out of the water.

To alleviate this situation and in particular to break down the water stratification, stirring by means of a wheel or screw-type agitator driven by an electric motor is commonly used with satisfactory results. The hydrogen sulphide, contaminating the interstitial waters of the bottom layer, may be eliminated by the application of iron-oxide (a residual product of copper refinery plants) at a density of 1–1·8 kg/m^2.

3.4.4 *Control of noxious sea weeds.* The whole area of a shrimp pond may frequently be covered by swarms of the green sea weed, *Ulva*. Subsequent decomposition of this alga seriously deteriorates both water and bottom soil, and causes a suspension in shrimp growth (Fig. 4). The swarming of *Ulva* is effectively checked by inducing and keeping a bloom of unicellular planktonic algae such as diatoms.

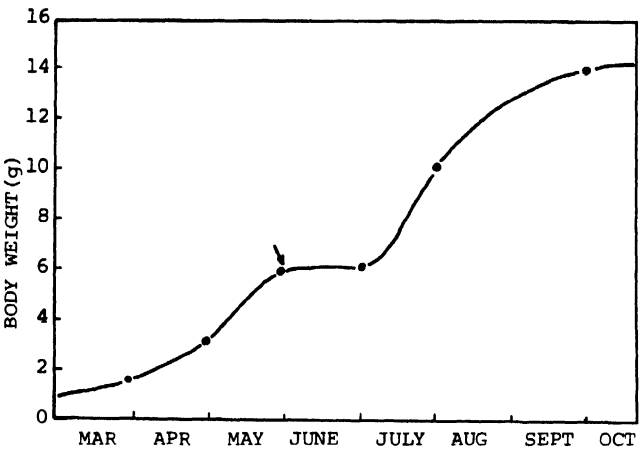


Fig 4. Growth curve of the kuruma shrimp cultured in pond, showing temporary suspension, indicated by arrow, due to swarming of *Ulva*

3.5 *Harvest*

Pond-grown shrimp may be first harvested as early as mid-August in order to thin out crowded stock. However, full-scale harvest usually begins in October and lasts until December. Until mid-November, while the water temperature in the pond is still warm enough to allow active movement of the shrimp, they are commonly harvested at night with a pound net. As the water temperature decreases, the pound net becomes ineffective because of the shrimp's inactivity. They are then harvested during the day, using a dragnet attached to an iron frame with an electric shocker, or with water jet nozzles to stir them out from the bottom.

3.6 *Treatment of product*

Harvested shrimp are immediately transferred to a chilling tank. The water temperature in the tank is lowered gradually over a period of at least eight hours to a level at which the shrimp become inactive but which still allows movement of their walking legs and swimmerets. The shrimp are then sorted by size, their excess moisture removed, and they are weighed and packed in cartons with dry cool sawdust.

3.7 *Shipping and distribution*

Shrimp are air-shipped to remote markets, and transported by rail or truck to nearby markets. These shrimp are collected by a receiving agent and sold to middlemen by auction. Restauranteurs and retailers purchase the shrimp from the middlemen and sell them to consumers. There are thus at least three agents intervening between producer and consumer, each taking a commission of 5% or more.

The Tokyo Fish Market received a total of 447·8 tons of live kuruma shrimp in 1974, of which 229·6 tons (51·3%) were supplied by pond culture, 157·6 tons (35·2%) by domestic fisheries and 60·3 tons (13·5%) from abroad. Supply from domestic sea fisheries is usually concentrated

to the period from May to September and that from other sources to the rest of the year.

3.8 *Production costs and selling price*
The basic production cost per kg of live kuruma shrimp (excluding depreciation of equipment and installations) has been estimated by Shigueno (1975) to be Yen 2 828, of which 42% is spent on feeds, 18% for wages and 17% for marketing.

The market price of live kuruma shrimp depends on size and fluctuates daily as well as seasonally. In 1974, the monthly average of wholesale prices at the Tokyo Central Fish market was generally higher in March-May, when it attained a maximum of Yen 5 400/kg; and lower in September-November, hovering in the neighbourhood of Yen 3 300–3 700/kg.

3.9 *Problems and prospects*
The establishment of the first shrimp farms in 1963 prompted many enterprises to follow suit. By 1974 almost 50 enterprises were involved with shrimp culture activities in the districts of Amakusa, Seto Inland Sea and elsewhere in Japan, with a total pond area of 245 ha, producing almost 600 tons of live kuruma shrimp.

With rapid expansion of shrimp culture, several problems have come to light. The annual production was limited to about 2 tons (ca. Yen 8 million) per manpower and 250 g (ca. Yen 1 000)/m^2 of pond surface. These values are very low compared to those in other domestic industries. Fresh short-necked clam and blue mussel are too expensive to feed shrimp. Their supply has been limited in recent years, and severe limitations are anticipated in the future.

To cope with these situations, efforts are being concentrated to develop: (*i*) a suitable compounded feed, and (*ii*) a new culture method in which the environmental conditions are effectively controlled. The formula feed has already been accepted in many shrimp farms and its demand is rapidly increasing. A consumption of almost 600 tons is anticipated in 1976. The nutritional requirements of kuruma shrimp are in need of further studies to improve the formula feed, in particular with regard to its feeding efficiency during the summer months.

To improve the productivity of shrimp culture, an intensive method has been developed in Kagoshima Fisheries Research Station (Shigueno, 1975). The basic principle is to maintain clean water and aerobic conditions on the bottom, combined with the use of formula feed. Results from preliminary experiments are promising. The possibility of producing two crops annually, each of 2·1–2·6 kg/m^2, is contemplated—provided that a highly efficient formula feed and warm water are guaranteed.

4 Farming the sea

Success in the mass production of kuruma shrimp fry has led to stocking the sea to supplement local shrimp yields. Considerable scientific efforts have been devoted during the last decade, with financial support by both the central and the prefectural governments, to the development of proper methods of release whereby the survival rates of hatchery-reared shrimp fry can be maintained at reasonably high levels. Several methods have been developed; their effectiveness and limitations are discussed below. Generally, there are two practices: one with pre-stocking rearing and the other without.

Any techniques aiming at the control of biological production must be fitted to the physiological and ecological characteristics of the particular species being cultured. The methods described below are, therefore, intended primarily for this species. Application of these methods to any other species of shrimp will require modifications.

4.1 *Fitness of fry for stocking*
The fitness of shrimp fry for stocking purposes varies according to their size or developmental stage. Kuruma shrimp is a typical burrowing species and once benthic, it tends to burrow into the substrate and become more or less sedentary within a well defined area, except for a gradual offshore movement associated with growth. This behaviour, which is very important for the recognition of hatchery recruits released in the sea, is acquired by the hatchery-reared juveniles when they attain an average body length of about 10 mm, while the corresponding size in natural stocks is 7–9 mm.

If the fry are very young they disperse or move so far from the release site that they can hardly be traced, even on the following day. On the other hand, if they are reared in the hatchery tank for a longer period, the walking legs and swimmerets of a large number of individuals become abraded due to friction against the concrete walls or against each other. Disease and loss of locomotion and burrowing capabilities can follow. In addition, when transported, they require much space per individual and are still apt to lose viability.

The habitat of a particular age group is quite restricted. For example, immediately following adoption of a benthic existence at 7–9 mm body length, the natural habitat is close to shore on intertidal flats. During any other stage in the life history their habitat is more extended. This situation makes it difficult to control their environment except at high cost.

4.2 *Stocking*
4.2.1 *Selection of stocking site.* Theoretically, the most suitable place for stocking is exactly the location where the maximum concentration of natural recruits is to be found. As mentioned earlier, the greatest concentration of early benthic juvenile kuruma shrimp is usually found on the sand flats between Mean Low Water Neap Tide (MLWNT) and Mean Sea Level (MSL), where the substrate is exposed at low tide leaving many shallow pools, and covered by only a few metres of water or less at high tides.

Hatchery-bred shrimp fry are usually planted at low tide into such pools which may or may not be surrounded by a net fence. When planted inside a net fence or a man-made lagoon, they are later liberated by simply removing the fence or knocking down the dikes.

4.2.2 *Initial mortality.* Upon liberation, hatchery-bred shrimp fry almost always suffer a more or less severe initial mortality. Such mortality has never been observed among natural recruits which are well adapted to the conditions prevailing on intertidal flats.

Preliminary experiments have shown that the initial loss occurs within 24 h after liberation. Among the survivors which have passed the period of initial mortality, the rate of loss becomes less severe and fairly constant and is almost

comparable to that of natural recruits. It is justifiable, therefore, to distinguish the fry mortality which occurs within 24 h after liberation from that during the remaining period of their life at sea, and to concentrate efforts on the determination of causes for the initial loss so that a method to minimize this loss can be developed.

4.3 *Factors affecting initial mortality*

4.3.1 *Physical and chemical factors.* Any one factor or combination of factors which generally limits the geographic distribution of kuruma shrimp in nature may well be responsible for the initial mortality. Unfavourable temperature, salinity, or dissolved oxygen content, or turbulence, *etc*, may kill substantial numbers of the released fry. Experiments and field observations have shown, however, that any single factor or combination of factors so far encountered on the intertidal flats of the Seto Inland Sea seldom exceeds the tolerance limit for shrimp fry. In fact, the serious initial mortality occurs in many cases without any detectable detrimental changes in the physical and chemical environment.

4.3.2 *Competitors.* Competition with other shrimp species does not seem to play an important role in the variation of the initial mortality, as each species has its particular preference for substrate and elevation relative to the tidal rise and fall and occupies more or less different sites within the general area between tidal marks.

4.3.3 *Predatory invertebrates.* The hermit crab, *Pagurus dubius*, and the gastropod *Niotha livescens* are reported as the main invertebrate predators of juvenile shrimp (Hiramatsu, Tako and Ishida, 1972). These animals are abundant on the intertidal flats where their habitat coincides closely with that of kuruma shrimp juveniles in the Seto Inland Sea. Hermit crabs are hunters of small moving animals without apparent selection. They are active during the daytime and able to forage as far as 1·5 km/day. Predation on the released shrimp fry may be disastrous only when the salinity is lowered to about 4–5 ppt and activity of the shrimp fry is impaired, while the hunting activity of the hermit crab is still maintained at a normal level. The gastropod is generally active at night but even during daytime preys on the released shrimp fry. Its predation may be serious only when water temperature exceeds 35°C and activity of the shrimp fry is more or less impaired, while the feeding activity of the gastropod still remains normal.

In conclusion, known invertebrate predators rarely seem to exert a disastrous influence on released shrimp fry unless fry activity is otherwise depressed.

4.3.4 *Predatory fish.* Fish are the most important predators of shrimp. Their predation on released shrimp fry is limited to the period of high tide, as many of them are carried away from the intertidal flats by the receding tides. The goby (*Gobius gymnauchen*) and young flatfish, however, remain within exposed pools during low tides, and prey on the released shrimp fry while moving around searching for a place to burrow.

Examinations of the stomach contents of gobies captured in such a pool within a few hours after shrimp fry liberation have revealed that an individual goby (3–7 cm in length) has preyed on as many as 110 shrimp fry. Kurata *et al* (1972) and Nozu *et al* (1975) have carried out field surveys to estimate the amount of predation and found that as much as 60% of the total initial mortality could be attributed to goby predation within a few hours after fry liberation.

4.4 *Pre-stocking rearing*

Predation can, of course, be eliminated by preventing contact between predator and prey. A fenced enclosure and man-made lagoon were constructed for this purpose and the shrimp fry reared within it with feeding continuing for a few days or weeks before liberation into open waters. Predator fish within the enclosure can be killed by treating the water with piscicides (see section 3.4.1) at low tide.

It soon became apparent, however, that the fenced enclosure was subjected to frequent damage due to wind, wave and tidal current. In addition, as the shrimp fry were confined at an extremely high density (1 000/m^2 or more) and their dispersion was limited, they were killed by adverse conditions such as heavy rain, hot weather, or typhoons.

Even with considerable labour and maximum possible care it is difficult to obtain a constant success in pre-stocking rearing with these methods. The survival rates so far reported at the end of such rearing are highly variable, ranging from almost 0 to as much as 70%. Few data are available on the survival rates of fry after liberation, but initial mortalities of 55–65% have been reported by Okayama Prefecture (1970), Miyazaki Prefecture (1971), and Kurata *et al* (1972).

In either of these methods it is unavoidable upon liberation not to leave the shrimp juveniles in nature without exposing them to predatory attacks of fish. The higher the survival rates during the rearing the more exaggerated is the crowded condition and the greater the invitation to intensified predation. To overcome this inherent difficulty other methods without confinements of shrimp fry are required.

4.5 *Artificial tideland as a stocking site*

4.5.1 *Principle.* The basic principle of this method is to control the environmental conditions at such a level as to preclude foraging of predatory fish, including gobies, and yet to permit a sedentary life of the hatchery-reared shrimp fry. The 10 mm long shrimp fry are directly released without any pre-stocking rearing or confinement.

4.5.2 *Control of physical conditions*

(*i*) *Elevation.* Preliminary experiments have shown that the initial loss of released fry tended to be less in pools at higher elevation than in those at lower elevation. As many as 120/m^2 of liberated fry have been found for at least five days after liberation in pools at Mean High Water Level of Neap Tide (MHWNT) if the water in the pool was maintained during exposure by mechanical pumping (Table II). This elevation is about 40 cm higher than MSL, the observed highest elevation for the natural recruitment of early benthic juveniles. A still greater density of survivors may be expected at higher elevation than MHWNT. However, the free dispersion of the shrimp fry, associated with their growth, will be limited, as the duration of one exposure increases progressively and exceeds 24 h at a little higher level than MHWNT. It is, therefore, necessary to crop and transfer the shrimp to the sea, which involves considerable manpower, to allow them further growth.

(*ii*) *Shallowness of the pool water.* The 10 mm long shrimp fry can and do live even in a few mm of water, while gobies, other than very small harmless ones, are seldom found in such shallow water. As a consequence, initial mortalities of the liberated shrimp fry are usually much less in very shallow pools than in the deeper ones.

(*iii*) *Hardness of substrate.* Gobies stay buried in the substrate of the pool exposed at low tide if the bottom is soft enough, and may emerge and prey on shrimp fry released there. A comparatively hard bottom with only a few mm of loose sediment on the surface, is much more favourable for the stocking of shrimp fry.

(*iv*) *Maintaining water and its quality.* On natural sand flats, exchange of water in an exposed pool is effected by a gradual flow of water from flats at a higher elevation. In man-made pools at a level of MHWNT, however, sufficient supply of water from the upper flats cannot be expected, and the water and its quality should be maintained by continuous pumping of fresh sea water during every exposure.

(*v*) *Current and waves.* Shrimp fry may be displaced by a current greater than 0·3 m/sec (Iikura, 1975). Current velocity and wave strength at the stocking place should be controlled within the above limit through construction of breakwaters, which also serve to protect the artificial tideland from erosion.

4.5.3 *Carrying capacity.* In 1973–74, an artificial tideland of commercial scale was constructed at Aio, Yamaguchi (Fig. 5). This tideland is composed of two sectors: a stocking zone and a transfer zone. The stocking zone is 1 ha (50 × 200 m) at MHWNT level. It is inclined seaward at a slope of 1/200, and is divided into 32 rectangular blocks (each 12·5 × 25·0 m) by concrete septa buried in the substrate leaving the upper 5 cm above sand. The transfer zone is 1·4 ha (70 × 200 m) at MSL, and links the stocking zone to the natural sand flats fronting the tideland. The whole area is covered at low tide by less than 5 cm of water supplied by pumping during every exposure. Duration of one exposure varies with tides: it is 15–16 h a day during spring tides, and 18–20 h a day during neap tides (Hagino, 1975).

In July-October of 1974, a total of 6 million shrimp fry were released in the stocking zone of this tideland. It was found that the stocking zone was able to harbour a maximum of 1 million newly liberated fry (100/m^2) at a time, or to carry about 3 kg (3 g/m^2) of shrimp juveniles of varying sizes (Umezawa *et al*, 1975). Stocking of more than 100/m^2 is only a waste of shrimp fry. It would be far more preferable to stock one million fry twice, with an interval of two to three weeks, than to stock 2 million fry at a time.

As they grow, the survivors gradually move from the stocking zone to the transfer zone and then to the natural sand flats to grow into marketable shrimp. By the time they attain an average body length of 25–30 mm, about two to three weeks after liberation, the majority of the survivors have left the stocking zone for deeper waters and the stocking zone is again ready to receive another recruitment of shrimp fry.

4.6 *Identification of hatchery output*

Identification of the hatchery output in field surveys is of prime importance to obtain any reliable evidence of the effectiveness of the stocking practice, as the commercial catch is usually composed of many age groups appearing in succession. Owing to their more or less sedentary mode of life, the age group of kuruma shrimp juveniles living on the intertidal areas may be distinguished by analysing size frequency distributions from samples taken at bimonthly intervals until they attain lengths of 6–8 cm, when certain fractions of them are captured, tagged and released for further identification.

Age groups or the hatchery recruits represented in the commercial gillnet catch may be distinguished by examining the data on: (*i*) the time and amount of stocking and of wild recruits on the nearby nursery areas; (*ii*) the growth rate of shrimp by season and by their own size; (*iii*) the size compositions of the commercial catch at frequent intervals, and (*iv*) the extent in time and space of dispersion/movement of the tagged individuals (see Fig. 6).

Identification of age group or hatchery output from particular inshore water represented in the offshore trawl catch is by no means easy, as the trawl catch is always composed of a number of recruits from many nursery grounds and from different inshore waters. Only the mark-recapture method gave a rough estimate.

4.7 *Practical value of stocking*

4.7.1 *Recovery rate.* Although it is comparatively easy to produce shrimp fry for stocking purposes, there is no conclusive evidence of the effect of their stocking on the subsequent yield of marketable shrimp. Such evidence may be obtained either indirectly, by analysing catch statistics before and after liberation, or directly by tracing a particular group of stocked fry from liberation until subsequent commercial catch.

The general sequence from the liberation of fry to their commercial catch as adults is as follows. When they are

TABLE II

VARIATION IN THE SURVIVAL OF HATCHERY-REARED KURUMA SHRIMP FRY IN RELATION TO THE ELEVATION OF THE PLACE OF RELEASE ON AN EXPERIMENTAL TIDELAND (KURATA ET AL, 1973 AND KURATA, 1974)

Elevation above datum level (cm)	*Tidal level*[1]	*Date of release*	*No. of fry released (×10^3)*	*Effective area (m^2)*	*Survivors 24 h after release per m^2*	
					Mean	*Maximum*
228–235	MHWNT	11/8/1972	70	1 100	42·6	116
		24/8/1973	102	1 500	46·9	
193–198	MSL	11/8/1972	87	1 680	4·8	38
		30/7/1973	69	1 800	9·6	
114–135	MLWNT	11/8/1972	96	1 800	1·2	14
		30/7/1973	66	1 500	8·9	

[1] MHWNT—Mean High Water Level of Neap Tide. MSL—Mean Sea Level

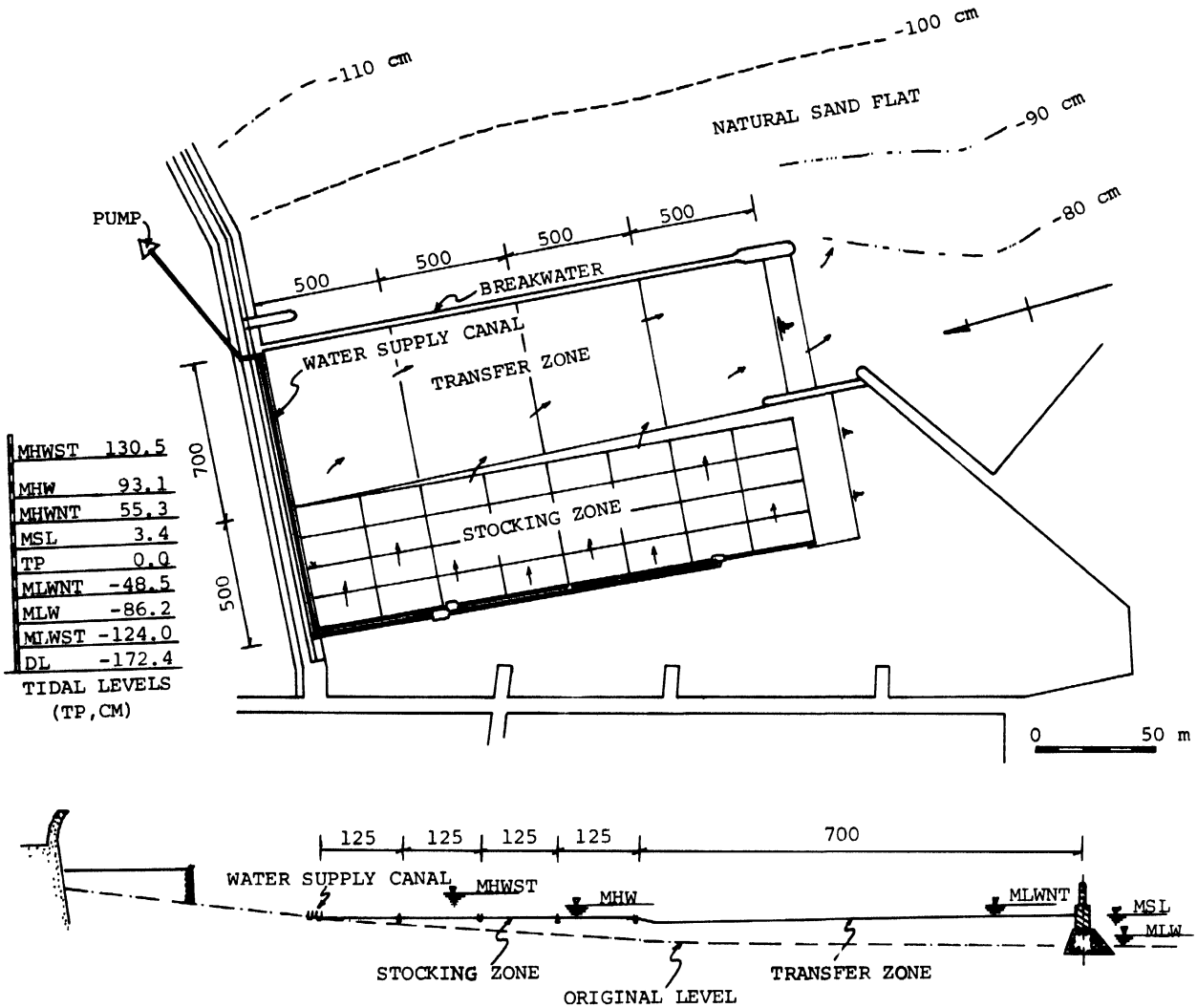


Fig 5. The floor plan (upper) and a cross-section (lower) of the artificial tideland of commercial scale constructed at Aio, 1973–74. Arrows indicate directions of water flow (from Nakamura and Uekita, 1975)

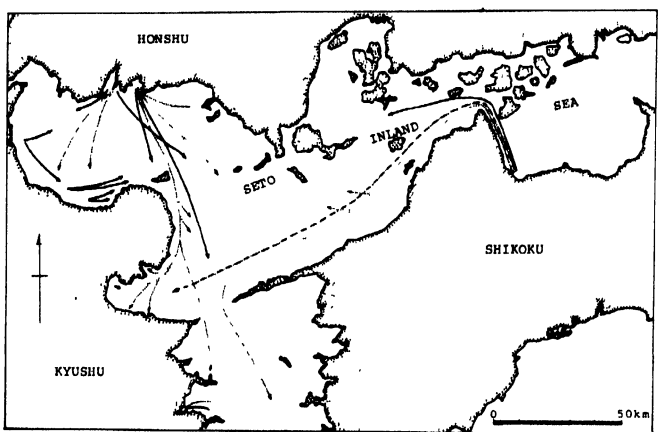


Fig 6. Migration of the tagged kuruma shrimp in the western Seto Inland Sea, 1970–74 (From Ishioka, Guema and Hasegawa, 1974; Ishioka and Guema, 1975)

liberated in May-June they appear, with average lengths of 11–13 cm, in the gillnet catches which are made out in the sublittoral zone within the bay from late Augut until the end of November. Shrimp are on their way to offshore grounds and their movement is apparently accelerated by decreasing temperatures. Few of them are represented in gillnet catches during the spring of the following year. On the other hand, when fry are stocked in August-October they appear in the gillnet catches from late May until early August of the following year, again on their way to offshore grounds to spawn. Outside the bay and elsewhere along the migratory route on the offshore grounds, the shrimp are further subject to commercial fishing by trawlers fishing throughout the year with a brief suspension in summer.

The indirect data reported so far with respect to recovery of stocked kuruma shrimp are inconclusive and subject to controversy, emphasizing the leading role of natural fluctuation. An example showing a possible correlation between hatchery output and subsequent increase in shrimp catch is given in Fig. 7. However, a parallel fluctuation in commercial catch is also noted in other bays where no substantial hatchery output has been liberated.

Some of the direct evidence (see Table III) which has recently been obtained is considered reliable to varying degrees. The values obtained for the fry liberated at Saijo in 1971 appear to approximate best to the true recovery rate, as the hatchery output has been traced almost completely along their migratory route in both time and space from inshore to offshore fisheries. Recoveries at other places include only those taken by inshore gillnetters and trawlers working close offshore and thus must be considered as minimum estimates.

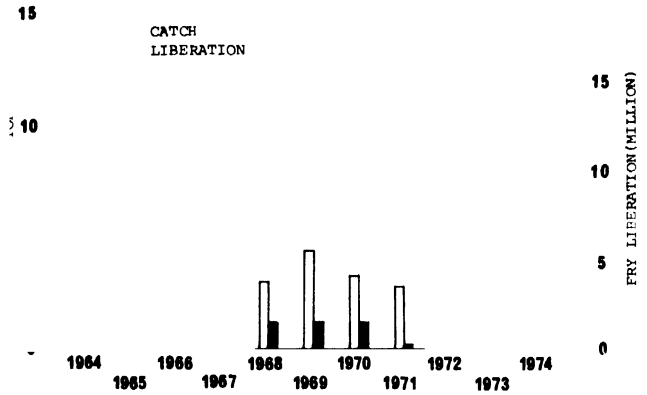


Fig 7. Fry liberation and catch data from Ohmi Bay (from Hiyama and Hara, 1975)

4.7.2 *Cost-benefit analysis.* Evaluation of the stocking practice on a cost-benefit basis appears to be premature. However, certain aspects of stocking may be analysed from this point of view. Shrimp fry are considered as effective when they survive beyond the period of the initial mortality. The cost of effective fry thus varies greatly with survival rates at liberation.

Hasegawa *et al* (1973) calculated for the hatchery output at Saijo, in 1971 (see Table III) that the net profit produced per individual (in this case Yen 1·9 each) is about Yen 5 when only the recovery by gillnetters is considered. On the other hand, it was estimated to be about Yen 20 when the recovery by offshore trawlers was also taken into account.

4.8 *Problems and future outlook*

The recent enthusiasm for stocking of fish and shellfish fry in Japan may be regarded in principle as a revival of hatchery liberation once common in many parts of the world at the turn of the present century. In practice, however, fry liberation today is quite different from an earlier epoch because the fry are reared until they become benthic and consequently their survival in nature is substantially improved, as was projected by Hjort and Dahl (1900). Their criticism of the seafish hatchery methods, as they were then practised, is noteworthy.

There is a general agreement among certain segments of the public as well as among the shrimp fishermen in Japan that the liberation of sedentary fry of kuruma shrimp is not only capable of increasing substantially the local shrimp production but also of supporting a considerable fishery, if adequate quantities of fry are liberated according to an organized plan. It is, therefore, not the effectiveness of the technique itself but improvement in the economic feasibility and cost-benefit ratio that the stocking practice of kuruma shrimp fry has to face.

The artificial tideland appears so far to be the most promising as a site for release of hatchery-reared kuruma shrimp fry. The technical problems which need further study are: (*i*) how to promote development of food organisms on the tideland so that the growth of the released fry can be accelerated; (*ii*) how to prevent accumulation and subsequent decomposition of large sea-weeds, such as *Ulva*, which cause serious deterioration of the sand bed, and (*iii*) to displace the larger sedentary juveniles, which are able to live in deeper water, so that the stocking zone becomes available again for the next batch of hatchery output.

A new problem now arising concerns the organizations which are farming shrimp. It is a thought-provoking question whether or not those which have released shrimp fry at their own expense will be granted an exclusive privilege to catch the resultant resources and, if granted, to what extent.

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TABLE III

RECOVERY OF KURUMA SHRIMP. (DATA FROM GILLNETTERS AND TRAWLERS ARE COMBINED. THEIR SHARE DIFFERS BY LOCALITY AND BY WEATHER CONDITIONS)

Place of release	*Month of release*	*No. of fry released* ($\times 10^3$)	*No. of survivors just after initial loss* ($\times 10^3$)	*Recovery by commercial catch* ($\times 10^3$)					*Percentage recovery in terms of*		*Source of data*
				1971	*1972*	*1973*	*1974*	*Total*	*Released fry*	*Survived fry*	
Saijo	June–July 1971	9 600	1 850	409	134	--	--	543	5·66	29·3	Hasegawa *et al* (1973)
Ohmi Bay	June–Sept. 1972	10 700	—	—	94	37	—	131	1·22	—	Hiyama and Hara (1975)
Ohmi Bay	June–Sept. 1973	8 000	1 490	—	—	85	43	128	1·60	8·8	Hiyama and Hara (1975)
Ohmi Bay	June 1974	2 000	130	—	—	—	14	14	0·70	10·9	Hiyama and Hara (1975)
Ohmi Bay[1]	July 1974	2 000	800	—	—	—	139	139	5·57	17·4	Hiyama and Hara (1975)
Saeki Bay	June 1973	2 700	496	—	—	34	21	55	2·04	11·1	Tashibu, Nozu and Itabashi (1975)
Saeki Bay	May–June 1974	2 400	287	—	—	—	39	39	1·63	10·5	Tashibu, Nozu and Itabashi (1975)

[1] Shrimp fry were liberated on the artificial tideland

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El Cultivo de Camarones Comerciales Peneidos en la Argentina y la Posibilidad de su Producción en Mayor Escala

E. E. Boschi y M. A. Scelzo

Extracto

Se han realizado cultivos en pequeña escala de los camarones peneidos *Hymenopenaeus muelleri* y *Artemesia longinaris*, especies de importancia comercial en el litoral marítimo de Argentina. Ambas especies han sido criadas a partir de hembras impregnadas y en madurez sexual, obtenidas en la región de pesca comercial. Se completó, en condiciones experimentales, el desarrollo larval de estas especies y el crecimiento de las primeras postlarvas de *H. muelleri* ha sido en promedio de 0,34 mm por día, llegando los juveniles, luego de 150 días, a una talla media de 61 mm y un peso medio de 2,7 g. Para *A. longinaris* se estableció un crecimiento de 0,4 a 1,0 mm por día, llegando en 150 días a una talla de 61 mm y en peso medio de 1,4 g. El alimento suministrado fue basado en una dieta preparada con calamar y crustáceos, complementada con sales minerales y vitaminas, con buenos resultados.

Se proyecta ampliar los trabajos en el futuro próximo, mediante cultivos en estanques y piletas externas e internas.

The culture of commercial prawns (penaeids) in Argentina and the possibility of producing them on a large scale

Abstract

Culture of the penaeid prawns *Hymenopenaeus muelleri* and *Artemesia longinaris*, commercially important species in the coastal waters of Argentina, has been undertaken on a small scale. Both species have been bred from impregnated and sexually mature females obtained in the commercial fishery. Larval development of both species was completed under experimental conditions. Growth of the first post-larvae of *H. muelleri* averaged 0·34 mm a day, and juveniles reached an average length of 61 mm and an average weight of 2·7 g in 150 days. For *A. longinaris* a growth of 0·4–1·0 mm a day was established; they attained a length of 61 mm and an average weight of 1·4 g in 150 days. Good results were obtained by feeding them on a diet prepared with squids and crustaceans, supplemented by mineral salts and vitamins.

It is planned to expand the work in the near future through culture in tanks and indoor and outside pools.

Elevage des crevettes pénéides à des fins commerciales en Argentine—possibilité de production à grande échelle

Résumé

On a pratiqué l'élevage à petite échelle de crevettes pénéides *Hymenopenaeus muelleri* et *Artemesia longinaris*, espèces ayant une importance commerciale, sur la côte de l'Argentine. Les deux espèces ont été produites à partir de femelles matures fécondées provenant d'exploitations commerciales de la région. Le développement larvaire de l'une et l'autre a été réalisé dans des conditions expérimentales et la croissance des postlarves de *H. muelleri* a atteint en moyenne 0,34 mm par jour, ce qui a mené les juvéniles en 150 jours à une taille moyenne de 61 mm et à un poids moyen de 2,7 g. Pour l'espèce *A. longinaris* on a déterminé une croissance de 0,4 à 1 mm par jour, les individus atteignant en 150 jours une taille de 61 mm et un poids moyen de 1,4 g. La nourriture administrée, à base de poulpes et de crustacés, complétée par des sels minéraux et des vitamines, a donné de bons résultats.

L'on prévoit d'élargir ces travaux dans le proche avenir par l'élevage à l'intérieur et à l'air libre en étangs et en bassins.

1 Introducción

En el Atlántico Sudoeste, en las aguas costeras de Argentina, existen dos especies de peneidos de valor comercial y en explotación pesquera actual. Uno es el llamado 'langostino' *Hymenopenaeus muelleri* de color rosado-tomate y de una longitud total en las tallas comerciales entre 45 y 160 mm, el otro es el 'camarón' *Artemesia longinaris* de color pardo, de una longitud entre 40 y 135 mm. La primera especie es la más importante en la pesca comercial por su mayor tamaño, pero el camarón debido también a la excelente calidad de la carne, es muy cotizado en el mercado de consumo y se emplea muchísimo como carnada en la pesca deportiva. Ambos peneidos se pescan comercialmente en la Argentina en las aguas bonaerenses y norte de la Patagonia, incluidas dentro de la subregión templada-cálida, con temperaturas entre 7 y 22°C.

Los trabajos sobre cultivos experimentales del langostino y el camarón se están realizando en el Instituto de Biología Marina, Mar del Plata y los resultados obtenidos son alentadores y promisorios y permiten considerar la posibilidad de realizar los mismos a mayor escala.

La producción pesquera actual de estos importantes camarones de aguas marinas de Argentina es muy fluctuante y no cubre la demanda interna. La extracción de ambas especies en los últimos años ha tenido tendencia a disminuir, con excepción de algunas capturas máximas en regiones como Bahía Blanca y Mar del Plata, Provincia de Buenos Aires. La producción total de las dos mencionadas especies de peneidos en Argentina fue de 600 toneladas para 1973.

2 Trabajos sobre cultivos

Las experiencias realizadas permiten asegurar éxito en el cultivo artificial de ambas especies (Boschi y Scelzo, 1971, 1974; Scelzo y Boschi, 1975). El langostino (*H. muelleri*) ha sido criado en cautividad a partir de hembras impregnadas y grávidas obtenidas en la región de pesca de las costas de Mar del Plata, 38°S, lográndose el desove en tanques

experimentales de 0,4 y 0,6 m^2 de superficie. El desarrollo del huevo y de las larvas se llevó a cabo con temperaturas que oscilaron entre 17 y 24°C, observándose una marcada diferencia en el tiempo del desarrollo larval en las distintas experiencias. Con temperaturas más bajas los estadios larvales se extendieron hasta 34 días, mientras que con temperaturas entre 19 y 24°C se redujo a sólo 19 días (Cuadro I).

Es interesante destacar que la temperatura entre 23 y 24°C en la cual se logró completar el desarrollo larval más acelerado, es entre 1 y 2°C mayor que la máxima que llega el mar costero en verano (febrero) en la región de Mar del Plata, donde en invierno la mínima puede estar entre 7 y 8°C. Ello naturalmente posibilita acelerar tanto las etapas larvales de la especie, así como el crecimiento de postlarvas y juveniles. Las postlarvas han crecido a razón de 0,34 mm por día en las primeras tres semanas. Luego de 62 días de vida se obtuvo un lote de juveniles con un largo total entre 17,2 y 28,2 mm. Estos mismos animales medidos a los 150 días tenían una talla entre 53 y 69 mm con un peso entre 2,1 y 3,7 g. Básicamente las postlarvas avanzadas y juveniles han sido alimentadas con dietas preparadas en el laboratorio, según la fórmula (*ii*) indicada más adelante.

Por otra parte las experiencias sobre tolerancia a cambios de salinidad y temperatura del langostino han demostrado que los juveniles, preadultos y adultos pueden vivir en aguas con salinidades normales (33,2–34,0 por mil) y mediante una adaptación gradual, a temperaturas que llegan a 25 y 26°C (Fenucci, Casal y Boschi, comunicación personal). Esto posibilita una mayor adaptación de la especie a distintos ambientes especialmente en estanques exteriores donde, en el transcurso de los meses de verano, la temperatura del agua puede elevarse por la intensa radiación solar. Tales cambios podrían ser un factor de estímulo en el crecimiento de la especie.

En cuanto al camarón (*A. longinaris*) los trabajos experimentales de laboratorio han permitido comprobar un apreciable crecimiento diario. En algunos casos las postlarvas y juveniles han crecido entre 0,4 y 1,0 mm diariamente en el primer mes de vida. Un lote de animales observados alcanzó tallas entre 50 y 68 mm de largo total a los 150 días. Esta tasa de crecimiento, durante los primeros dos meses, ha sido aparentemente mayor que el aumento de talla comprobado mediante muestreos de los animales obtenidos en los fondos de pesca comercial en algunos años fríos. Posiblemente la temperatura más alta y una alimentación más adecuada influyó para que los animales en cautividad crezcan más.

Hay que destacar finalmente que por ser dos especies de aguas templadas los peneidos estudiados, no crecen con el mismo ritmo que los camarones tropicales. Además *A. longinaris* es una especie de talla mediana y *H. muelleri*, aunque tiene un buen tamaño, no llega a la longitud de algunos *Penaeus*.

3 Alimentación

A los primeros estadios de postlarvas se suministró nauplii de *Artemia*. Cuando alcanzaron los 10 mm de longitud, se les alimentó en algunos cultivos con mejillón y carne de camarón picadas. Para las últimas experiencias se preparó un alimento artificial constituido por una mezcla de varios organismos marinos, con alto contenido en proteína cruda de alta eficiencia alimenticia para camarones peneidos (Deshimaru y Shigeno, 1972), sales minerales y vitaminas, que resultó adecuado para postlarvas avanzadas, juveniles y adultos. Las mezclas preparadas tenían los siguientes ingredientes:

	Por ciento
(*i*) Mejillón (tamaño no comercial)	68,0
Carne de langostino y camarón no comercial	30,0
Complejos de vitaminas y sales minerales (Dayamineral)	2.0
Composición química	
Lípidos totales	5.9
Proteína cruda	57.6
Cenizas	9.3
(*ii*) Calamar y calamarete	82,0
Carne de camarón y langostino no comercial	16.0
Complejos de vitaminas y sales minerales (Dayamineral)	2,0
Composición química	
Lípidos totales	10.5
Proteína cruda	67.5
Cenizas	9.6

Los ingredientes fueron mezclados en una trituradora de carne y la pasta obtenida se dejó secar a temperatura de 45°C hasta llegar al 19 por ciento de humedad. El compuesto resultante se molió a tamaños granulados de 0,5, 1,0 y 2,0 mm, para suministrarlo a distintas tallas de postlarvas y juveniles. A los lotes de animales en observación se proporcionó una ración al anochecer y otra por la mañana. De acuerdo con los primeros resultados la segunda dieta resultó ser más eficiente.

4 Perspectivas futuras

Las investigaciones realizadas hasta el presente sobre el cultivo experimental de las dos especies de peneidos comerciales de las aguas del litoral marítimo de Argentina, han puesto de manifiesto la posibilidad de su crianza en cautividad, lográndose el crecimiento de ambas especies hasta tallas de adultos.

Sobre la base de estos resultados se ha proyectado la instalación de una planta piloto para iniciar, en condiciones más amplias que las actuales y empleando construcciones

CUADRO I

TIEMPO INSUMIDO EN EL DESARROLLO LARVAL Y EN EL CRECIMIENTO DE POSTLARVAS Y JUVENILES DE LAS DOS ESPECIES DE PENEIDOS CULTIVADOS

Especie	*Tiempo de desarrollo*		*Crecimiento medio de*			*Temperaturas °C*
	Huevo en horas	*Larval en días*	*La postlarva*	*Juveniles*		
				90 días	*150 días*	
Artemesia longinaris	12–36	24–32	5,0 mm	48 mm (0,8 g)	61 mm (1,4 g)	16 y 23
Hymenopenaeus muelleri	24	19–34	5,0 mm	22 mm	61 mm (2,7 g)	17 y 24

Nota: Las temperaturas mayores corresponden al menor número de días del desarrollo larval. Los resultados de crecimiento de los juveniles corresponden a observaciones efectuadas con lotes de aproximadamente 25 individuos

cubiertas y al aire libre, los trabajos en mayor escala, con el fin de incrementar la producción de ambas especies (Boschi, 1974).

En la crianza en estanques de cultivos, con temperatura superior a la del medio natural y con una alimentación adecuada, es posible lograr un significativo aumento de la tasa de crecimiento en un plazo más breve y con una biomasa de animales más alta por superficie.

El proyecto recomienda la ubicación de la futura Estación de Cultivos Marinos, cerca de la Albufera 'Mar Chiquita' a unos 40 km de la Ciudad de Mar del Plata, frente al mar y con canales artificiales con circulación de agua. El espacio inicial será de un cuarto de hectárea, para edificios, piletas de mampostería, bombas de agua salada con filtros, laboratorios y demás instalaciones complementarias. La intención es extender estos trabajos a moluscos bénticos de valor comercial como mejillones, vieiras, cholgas, almejas, etc., y algunas especies de peces (Boschi, 1974a).

Por otra parte se prosiguen las investigaciones tendientes a lograr la procreación en cautividad de ambas especies de peneidos, provenientes de cultivos experimentales. Otras investigaciones que continúan son las orientadas a perfeccionar el alimento artificial, para lograr una dieta adecuada a bajo costo.

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Penaeid Shrimp Culture Research at the National Marine Fisheries Service Galveston Laboratory[1]

R. A. Neal

Abstract

Recent research activities of the National Marine Fisheries Service Galveston Laboratory of the Gulf Coastal Fisheries Center directed toward the development of the background biological information on penaeid shrimp required by shrimp culturists are reviewed. Four general areas of research in penaeid biology and culture are described: maturation and spawning; nutrition and feeds; disease diagnosis and control; and intensive culture in controlled environments. Significant publications and progress resulting from this research are noted and the information in these publications is summarized. Present activities and planned areas of emphasis in the Laboratory's research projects include: experimentation to refine the method of *in vitro* fertilization of captive shrimp, further tests with diets to evaluate components, such as fatty acids, determining means of controlling and preventing shrimp diseases, and applying environment control systems developed at Galveston Laboratory to shrimp culture techniques.

Recherche sur la culture des crevettes pénéides au Laboratoire du National Marine Fisheries Service à Galveston

Résumé

On examine les récentes activités de recherche menées au Laboratoire du National Marine Fisheries Service du Gulf Coastal Fisheries Center à Galveston, USA, en vue d'élaborer les informations biologiques de base sur la crevette pénéide nécessaires aux éleveurs de crevettes. Quatre domaines généraux de recherche sur la biologie et la culture des pénéides sont décrits: maturation et frai; nutrition et aliments; diagnostic et lutte contre les maladies; culture intensive en milieu controlé. Les publications importantes et les progrès découlant de ces recherches sont indiquées, et les renseignements figurant dans ces publications sont résumés. Les activités présentes et les orientations futures des travaux de recherche du laboratoire sont les suivantes: expérimentation pour perfectionner la méthode de fertilisation *in vitro* des crevettes captives; poursuite des essais sur l'alimentation pour en évaluer les éléments tels que les acides gras, détermination des moyens de prévenir les maladies des crevettes et de lutter contre elles, et d'appliquer aux techniques de culture des crevettes les systèmes de contrôle de l'environnement mis au point au Laboratoire de Galveston.

Investigaciones sobre cultivo de camarones peneidos en el Laboratorio de Galveston del Servicio Nacional de Pesca Marítima

Extracto

En este trabajo se examinan las investigaciones realizadas recientemente en el Laboratorio de Galveston (Centro para las Pesquerías Costeras del Golfo, Servicio Nacional de Pesca Marítima) para reunir la información biológica básica sobre los camarones peneidos que necesitan quienes se dedican a su cultivo. Se describen cuatro sectores en los que se han realizado investigaciones en relación con la biología y el cultivo de peneidos: maduración y desove; nutrición y piensos; diagnóstico de enfermedades y su control; y cultivo intensivo en ambientes controlados. Se reseñan las publicaciones y progresos más importantes derivados de esas investigaciones y se resume brevemente la información contenida en las publicaciones mencionadas. Entre las actividades actuales y futuras de los proyectos de investigación en laboratorio figuran: experimentos para mejorar el método de fertilización *in vitro* de camarones cautivos; nuevos ensayos con raciones alimenticias para evaluar algunos componentes, como los ácidos grasos; preparación de medio para controlar las enfermedades de camarones y prevenirlas; y aplicación a las técnicas del cultivo de camarones de sistemas de control del medio ambiente desarrollados por el Laboratorio de Galveston.

1 Introduction

Research on the biology and culture of penaeid shrimp has been conducted at the Galveston Laboratory of the National Marine Fisheries Service Gulf Coastal Fisheries Center for a number of years. That portion of the activity oriented toward the culture of penaeid shrimp has been reviewed by Lindner and Cook (1971), Neal (1973), Neal (1974) and Neal (1975). Recent research activities and progress at the laboratory will be discussed including the solution of basic problems in four general areas of penaeid shrimp biology and culture.

2 Maturation and spawning

Earlier research concerning inducement of penaeid maturation and spawning in captivity was directed along two lines: experimental manipulation of environmental conditions and the formulation of suitable diets for maturing penaeids. Neither of these approaches resulted in a definitive solution. Partial ovarian development in some experimental animals led to the assumption that the factors: light intensity, light wave length, pH and some unknown chemical aspects of water quality, influenced maturation. While other unidentified environmental parameters may also affect development, no clear relationships between dietary components and maturation were established.

Because of the complexity of the problem of determining the role of water chemistry in maturation, and because of

[1] A contribution of the National Marine Fisheries Service, Gulf Coastal Fisheries Center, Galveston Laboratory, 4700 Avenue U, Galveston, Texas 77550, USA.

the need for a simple technique for maturing females in captivity, a new approach to the problem was initiated. This approach consisted of a thorough description of the normal reproductive processes at the light and electron microscopy levels, and experimental manipulation of the endocrine system of shrimp evaluated by comparison with the normal situation.

Much of the descriptive work on normal penaeid reproductive development has been done in co-operation with scientists from the University of Houston. The male reproductive system has been described by Lu and Clark (1975). Ovarian development is discussed by Duronslet *et al* (1975), and the cortical reaction is described by Clark, Lynn and Persyn (1975) and by Clark, Persyn and Yudin (1974).

This understanding of the normal reproductive process at the cellular and fine structural levels provides a basis for the comparison of normal and experimental animals. Using this tool, experimental manipulation of the endocrine systems has been initiated in conjunction with a thorough description of the effects of each technique tested.

The effects of the manipulation techniques, such as eyestalk ablation, apparently vary depending upon both the species and the environmental conditions. Our understanding of these interactions is incomplete. The results of work in Galveston with brown shrimp, *Penaeus aztecus*, have been described by Duronslet *et al* (1975). Ovarian development can be induced routinely by eyestalk ablation, and spawning has been induced in a few ablated shrimp; spawning of these shrimp is still, however, apparently a major problem. Diener, Yudin and Clark (1975) have identified the ecdysial gland of the blue crab, *Callinectes sapidus*. Transplants of this gland and its extracts have pronounced effects on shrimp moulting, but the effect on gonadal development is not clear. The effects of injections of various insect and mammalian hormones are also poorly understood even though experimentation with these hormones is under way.

A tool which will have many applications in breeding studies, as well as in the spawning of captive shrimp on demand, is *in vitro* fertilization. A method for *in vitro* fertilization is described by Clark *et al* (1973) and experiments to refine the method are in progress.

3 Nutrition and feeds

The development of diets for penaeid shrimp has followed two separate paths: (*i*) the formulation of diets for rearing shrimp in semi-natural ponds where natural food is available; and (*ii*) the formulation of diets for use in tanks where little or no natural food is available. The objective of research on nutrition and feeds at the Galveston Laboratory is to develop suitable diets for use in tanks where water is being circulated. Research workers established that a worm-shaped extruded pellet is an acceptable form for juvenile and adult penaeid shrimp (Meyers and Zein-Eldin, 1972) and that a drum-dried flake is a suitable form for postlarval penaeids (Meyers and Brand, 1975; Mock, Neal and Salser, 1973). The most satisfactory binder found for experimental diets used in nutritional studies is an alginate (Meyers and Zein-Eldin, 1972). In addition, the attractant chosen for experimental research was fish solubles (Zein-Eldin and Meyers, 1973).

As the result of a long series of diet comparisons, a standard diet was established for use in experimental studies. This diet (5–5/7OB) will produce good growth of *Penaeus aztecus* and *P. setiferus* under experimental conditions and is designed to permit substitution of individual ingredients without gross modification of its nutritional characteristics (Zein-Eldin and Meyers, 1973). This diet has been used successfully in a number of high-density rearing experiments in closed raceway systems (Mock, Ross and Salser, 1975).

Experimentation over several years has led to the conclusion that the diets used at the Galveston Laboratory generally have a suitable amino-acid balance and that the 35–40% protein level is satisfactory within the constraints of the diet series tested (Fenucci and Zein-Eldin, 1978, and Zein-Eldin and Corliss, 1978). At this point other dietary factors seem to limit shrimp growth. Future experimentation with these diets is planned, therefore, to evaluate other dietary components, such as fatty acids.

4 Disease diagnosis and control

The objective of the shrimp disease research programme of the National Marine Fisheries Service in Galveston is to conduct studies necessary to identify, treat and prevent diseases in penaeids under culture conditions. The research activities have fallen into three broad categories: (*i*) description of normal tissues and normal responses to injury or foreign materials; (*ii*) description of shrimp pathogens and studies of their effects on shrimp; and (*iii*) studies of methods of preventing and treating diseases.

The normal tissues of several organs of shrimp as well as normal post-mortem changes are described by Lightner (1974). Wound repair processes of shrimp and crayfish (*Procambarus*) are discussed by Fontaine (1971), Fontaine and Dyjak (1973), Fontaine and Lightner (1973), and Fontaine (1975). The responses of penaeids to the introduction of foreign material is documented by Fontaine and Lightner (1974), Fontaine *et al* (1975), Sparks and Fontaine (1973), and by Fontaine and Lightner (1975).

Specific diseases which have been described are: a gas-bubble disease in *Peneaus aztecus* (Lightner, Salser and Wheeler, 1974); a mycosis of the American lobster, *Homarus americanus* (Lightner and Fontaine, 1975); and a fungal disease of *Penaeus setiferus* larvae (Lightner and Fontaine, 1973). In addition, a discussion of gill diseases in penaeids has been prepared by Lightner, Fontaine and Hanks (1975), and a review of published shrimp disease information on US species has been prepared by Lightner (1975).

Experimentation on means of preventing and controlling shrimp diseases has just begun. Diseases of captive shrimp frequently occur in association with a known environmental condition that causes stress. The experience at Galveston Laboratory has been that in such situations the removal of the stress-inducing factor usually stops the spread of the disease. As a preliminary step to the treatment of diseases with antibiotics, the effects of oral doses of two antibiotics, oxytetracycline and furozolidone, on normal shrimp were studied (Corliss, Lightner and Zein-Eldin, 1975; Corliss and Zein-Eldin, 1975).

5 Intensive culture in controlled environments

The goals of this research have been to develop dependable

methods for rearing shrimp at high densities, under controlled conditions, on a year-round basis. As winter temperatures in Texas ponds are lethal to penaeid shrimp, considerable research on temperature control has been conducted to find economical means of providing optimum temperatures for continuous growth. This temperature control work has led to recycling of water and consequently to the development of systems for water treatment and re-use.

The first phase of this research, that of improving hatchery techniques, had been completed. The methods developed permit the routine production of uniformly healthy, vigorous postlarvae in about 10 days from hatching with survival rates exceeding 80% from hatching. These methods, which are used by several industrial groups, are discussed in papers by Mock and Murphy (1971), Mock and Neal (1974), Salser and Mock (1974), and Mock (1974).

The second phase has been the development of larger closed systems for rearing postlarval and juvenile penaeids to an intermediate size (30–60 mm) for subsequent restocking in larger pond or raceway systems. Research on these techniques is also nearing completion. Methods described by Mock, Neal and Salser (1973) and by Mock, Ross and Salser (1975) have proved to be efficient and dependable for rearing small shrimp at high densities with good survival. During these experiments, postlarvae have been reared at densities of 2 300/m^2 (22 mm), 12 500/m^2 (12 mm) and 26 100/m^2 (16 mm) with survival rates of 90–95%. Juveniles have been reared at densities of 100/m^2 (88 mm) to 1 600/m^2 (31 mm) with survival rates ranging from 80 to 97%.

During the second as well as the third phase in the production of marketable-size shrimp in closed raceway systems, the limiting factor has been the accumulation of wastes in the systems. In efforts to increase production per unit area in these systems a variety of water treatment methods has been tested. Treatment techniques tested were those which permitted easy recovery of solid wastes or biological growths, required relatively small capital outlay and low operating expenses, and could be automated readily. Techniques which have been or are being tested are discussed by Mock, Neal and Salser (1973), Mock, Ross and Salser, (1975), and Neal and Mock (1978). Waste treatment methods used in the system at present are water aeration, particulate removal with inclined plate separators, and dissolved waste removal with biodisc filters and foam fractionation columns.

The design and construction of inexpensive tanks which permit a high level of environmental control have been the subject of detailed experimentation and developmental research. A simple portable raceway system consisting of walls constructed with fibreglass panels lined with styrofoam and supported by aluminium braces has been constructed. The system is lined with polyethylene and covered with a low-profile plastic cover. A floating centre wall is used to support the airlift pumps and one end of the raceway extends into a larger building where waste removal apparatus is housed (Mock and Neal, 1975).

In summary, the research on methods of controlling environmental conditions to increase production in raceways has resulted in the development of a number of new techniques which have practical applications in both raceway and pond culture of marine organisms. Practical applications of environmental control are seen in intensive, closed systems (for shrimp larvae and postlarvae) and in less intensive systems for larger shrimp and other marine organisms. The recycling of aquacultural wastes is a topic deserving considerable attention and research.

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Reproduction Controlée Chez la Crevette *Penaeus japonicus*[1]

A. Laubier-Bonichon et L. Laubier

Résumé
Le contrôle écologique des phénomènes de reproduction chez la crevette *Penaeus japonicus* élevée en captivité depuis les premiers stades larvaires n'a jamais été obtenu, bien que quelques observations partielles sur la ponte en captivité aient été signalées. Une série d'expériences, dans lesquelles la température et la durée quotidienne d'éclairement ont été rigoureusement contrôlées, a permis d'obtenir la maturation complète en trois mois d'une soixantaine de femelles d'un et deux ans (avril-juin). Durant les quatre mois suivants (10 juillet-10 novembre), 87 pontes totalisant 1 322 800 larves ont été recueillies. En même temps, la technique de ponte provoquée appliquée à des femelles isolées a permis d'obtenir une première ponte de 455 000 œufs avec un taux d'éclosion supérieur à 98%, puis une autre ponte de 159 000 œufs en deux nuits consécutives. Les conditions écologiques ayant donné les meilleurs résultats correspondent à un 'climat' tropical: température de 24°C et durée d'éclairement quotidien de 14 h 45.

Controlled reproduction of the shrimp *Penaeus japonicus*
Abstract
Reproduction of the shrimp *Penaeus japonicus* bred in captivity from the first larval stage has never been controlled ecologically, although partial observations have been made on the deposition of spawn by captive broodstock. A series of experiments, in which temperature and the daily duration of lighting were rigorously controlled, has made it possible to obtain complete maturation in three months from about 60 one- or two-year-old females (April-June). In the four months following (10 July-10 November), 87 depositions of spawn totalling 1 322 800 larvae were collected. At the same time, an induced spawning technique applied to isolated females has made it possible to obtain an initial deposition of spawn with 455 000 eggs with a hatching rate higher than 98%, followed by another deposition of spawn with 159 000 eggs in two consecutive nights. The ecological conditions yielding the best results were those of a tropical 'climate': temperature at 24°C and daily illumination lasting for 14 h 45 min.

Reproducción controlada del camarón *Penaeus japonicus*
Extracto
El control ecológico de los fenómenos de reproducción del camarón *Penaeus japonicus* criado en cautividad desde las primeras fases larvales no se ha conseguido aún, aunque se han realizado algunas observaciones parciales sobre el desove en cautividad. En una serie de experimentos con control riguroso de la temperatura y del fotoperiodo se ha logrado hacer llegar en tres meses a la madurez total a unas 60 hembras de uno y dos años (abril-junio). Durante los cuatro meses siguientes (10 julio-10 noviembre) se recogieron 87 puestas con un total de 1 322 800 larvas. Al mismo tiempo, la técnica de desove inducido aplicada a hembras aisladas ha permitido obtener una primera puesta de 455 000 huevos, con un índice de eclosión superior al 98%, y posteriormente otra puesta de 159 000 huevos, en dos noches consecutivas. Las condiciones ecológicas que han dado mejores resultados son las correspondientes a un 'clima' tropical: temperatura de 24°C y 14 horas 45 minutos de luz al día.

1 Introduction

Un des principaux problèmes auquel se heurte le développement des élevages commerciaux de crevettes pénaeides est celui de l'obtention de pontes à une période déterminée de l'année, en particulier en dehors de la période naturelle de reproduction. Chez *Penaeus japonicus*, il a été signalé récemment des maturations généralement suivies de régressions dans un élevage en climat tropical, quatre petites pontes ayant toutefois été obtenues (AQUACOP, 1975). D'autre part, la reproduction en captivité avec obtention de plusieurs générations successives aurait été obtenue dès 1962 au Japon (Takamatsu) par le Dr. J. Kittaka (comm. pers.). Jusqu'à présent, la reproduction de *P. japonicus* dans des conditions écologiques contrôlées n'était pas connue. Au cours d'une série d'expériences réalisées en 1975, nous avons obtenu la maturation sexuelle et la ponte chez de petites populations d'animaux soumises à des conditions de température et d'éclairement bien définies, et ces résultats apportent des données originales sur le comportement de ponte de cette espèce.

2 Matériel et méthodes

2.1 *Les géniteurs*

Les animaux mis en expérience sont issus de post-larves importées du Japon à la fin du mois de mai. Ils appartiennent à deux classes, les uns âgés de 23 mois, les autres de 11 mois, au début de l'expérience le 1er avril 1975 (dates de naissance ramenées au début du mois de mai de chaque année). La croissance des animaux avant la mise en expérience s'est effectuée dans des bassins à l'extérieur, et une partie des individus âgés a été maintenue pendant 10 mois à une température de 17 à 18°C. Le 1er avril 1975, 149 crevettes ont été réparties dans les trois bacs d'expérience selon le schéma suivant:

	Bac 1	*Bac 2*	*Bac 3*
Mâles 1 an	18	17	5
Mâles 2 ans	4	4	4
Femelles 1 an	20	18	4
Femelles 2 ans	4	5	4
Sexe inconnu	3	5	34
Total	49	49	51

Dans le bac 3, pour des raisons de pénurie de bassin à la suite des premiers développements larvaires, 7 mâles de 2

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ans (poids moyen 36 g) et 4 femelles de 2 ans (poids moyen 54,7 g) ont été ajoutés au stock initial le 11 août.

Le poids moyen des animaux au 1er avril était de 32 g pour les animaux de 2 ans et de 12 g pour ceux d'un an. poids relativement faibles témoignant des conditions d'élevage peu favorables. Durant l'expérience (1er avril-10 novembre), la mortalité naturelle a été limitée à la période initiale d'adaptation de trois semaines, et a atteint pour l'ensemble des bacs 4 individus, soit près de 3%. Par la suite, les mortalités enregistrées sont accidentelles (sauts hors des bacs) ou bien correspondent à des prélèvements pour études histologiques. La composition des populations au 10 novembre est la suivante:

	Bac 1		*Bac 2*		*Bac 3*	
	Nombre	*Poids (g)*	*Nombre*	*Poids (g)*	*Nombre*	*Poids (g)*
Mâles	21	45,6	14	44,0	26	44,7
Femelles	18	67,6	18	59,3	24	63,6

Il n'est plus possible de reconnaître à coup sûr toutes les femelles de 2 ans: une douzaine d'animaux de poids compris entre 75 et 96 g appartiennent certainement à cette classe.

Au 10 novembre, la charge atteint 407 g/m^2 dans le bac 3, 329 g/m^2 dans le bac 1, et 225 g/m^2 dans le bac 2.

2.2 *Les bacs d'expérience*

Les trois bacs, tous identiques, permettent de mener parallèlement trois essais en faisant varier indépendamment la température et la photopériode. Ces bacs, cylindriques, de 2,90 m de diamètre et de 1,50 m de hauteur, sont équipés d'un double fond communiquant avec un dispositif d'évacuation par trop-plein extérieur réglable. Un air-lift central en relation avec le volume du double fond entraîne la circulation et l'aération de l'eau (L'Herroux, 1974). Une couche de sable de 10 cm d'épaisseur disposée sur un feutre de tissu synthétique permet l'enfouissement normal des animaux durant la journée. La hauteur d'eau libre au-dessus du sable est de 1 m, ce qui correspond à un volume d'eau de 6,6 m^3. La circulation de l'eau dans chaque bac se fait en système semi-fermé: l'apport d'eau est de 450 l/h. Cette eau traverse en amont un bac de chauffage où elle est portée à la température désirée par un jeu de résistances chauffantes sous gaine de silice. La température de l'eau des bacs d'expérience est enregistrée en permanence par un thermographe à distance.

Chaque bac est isolé individuellement et totalement de la lumière extérieure, et l'éclairage est assuré par des tubes fluorescents suspendus à 50 cm au-dessus de l'eau, totalisant 14 600 lumens et donnant en surface de 500 à 1 500 lux selon la zone considérée. Les durées journalières d'éclairement sont commandées par trois interrupteurs horaires. Les autres facteurs physico-chimiques (salinité, taux d'O_2 dissous, pH, sels nutritifs, etc.) n'ont pas été contrôlés, mais se sont révélés très stables au cours des expériences: pH de 8,1 à 8,3, taux d'O_2 dissous très voisin de la saturation.

Dès l'observation des premières pontes dans les bacs, l'évacuation a été modifiée pour une récupération aisée des larves: un trop-plein superficiel se déverse dans un collecteur adapté d'un incubateur pour œufs de poissons équipé d'une poche à maille de 180 microns (Girin, 1976).

Les animaux sont nourris quotidiennement et à satiété de chair de moules. La distribution de la nourriture a lieu normalement en fin d'après-midi. Les déchets de nourriture sont retirés chaque matin.

2.3 *Facteurs écologiques expérimentaux*

Les animaux ayant subi jusqu'au début de l'expérience (1er avril 1975) les conditions d'éclairage naturel, on a choisi de reproduire expérimentalement le rythme nycthéméral pour la date et la latitude considérées, soit 12.45 h d'éclairement quotidien. La température dans les trois bacs est de 15°C au départ. Les variations de température et de photopériode réalisées dans les trois bacs sont reportées sur la Fig. 1. On a cherché à créer un bac chaud à durée d'éclairement longue (bac 1, 26°C et 16 h d'éclairement quotidien au 21 juin), un bac froid à durée d'éclairement courte (bac 3, 20°C et $13\frac{1}{2}$ h d'éclairement quotidien au 21 juin), enfin un bac moyen (bac 2, 24°C et $14\frac{3}{4}$ h d'éclairement quotidien au 21 juin). En ce qui concerne la température, on note sur la Fig. 1 un certain nombre de défaillances, heureusement de faible amplitude jusqu'au mois d'octobre; elles proviennent de défauts d'isolement des résistances, ainsi que de problèmes d'homogénéisation de la masse d'eau dans le bac de chauffage (apparition de phénomènes de stratification).

3 Résultats

3.1 *Maturation*

L'examen des animaux en expérience n'a pas été fait de manière systématique, pour éviter de perturber le déroulement des processus de reproduction. Lors de la mise en expérience, les femelles de la classe 1974 étaient toutes immatures; les femelles de la classe 1973 avaient des ovaires visibles par transparence, mais filiformes. Les premiers signes de maturation sont apparus à la fin du mois d'avril chez une femelle de la classe 1973 provenant du bac 2, après dissection (ovaires colorés en jaune). Le 12 juin, une femelle de deux ans montrait à la dissection des ovaires organés, avec un rapport gonado-somatique de 6. A la fin du mois de juin, toutes les femelles observées dans les trois bacs présentaient des ovaires bien développés, de teinte plus ou moins foncée à l'observation par transparence. Lors du recensement général du 10 novembre, une forte proportion de femelles, d'après la coloration et la forme de l'ovaire, etaient en cours de maturation ou prêtes à pondre 12 sur 18 dans le bac 1, 13 sur 18 dans le bac 2, et 18 sur 24 dans le bac 3. L'aspect de l'ovaire des femelles restantes ressemblait beaucoup à l'ovaire d'une des femelles ayant fourni une ponte importante par élévation de la température (cf. sect. 3.3).

3.2 *Pontes dans les bacs d'expérience*

La première ponte a été observée le 12 juillet dans le bac 2; les larves au stade zoé 1 correspondaient à une ponte survenue au cours de la nuit du 9 au 10 juillet. Dans les deux autres bacs, la première ponte a eu lieu quelques jours plus tard. Les dispositifs de collecte ont été mis en place dès l'observation de la première ponte. Dans le cadre de ces expériences, le terme 'ponte', qui recouvre peut-être l'émission simultanée d'œufs de plusieurs femelles, correspond simplement à l'ensemble des œufs ou des stades larvaires qui, d'après les vitesses de développement, ont été émis durant un intervalle de temps de plusieurs heures. En tout état de cause, le nombre de pontes indiqué constitue un

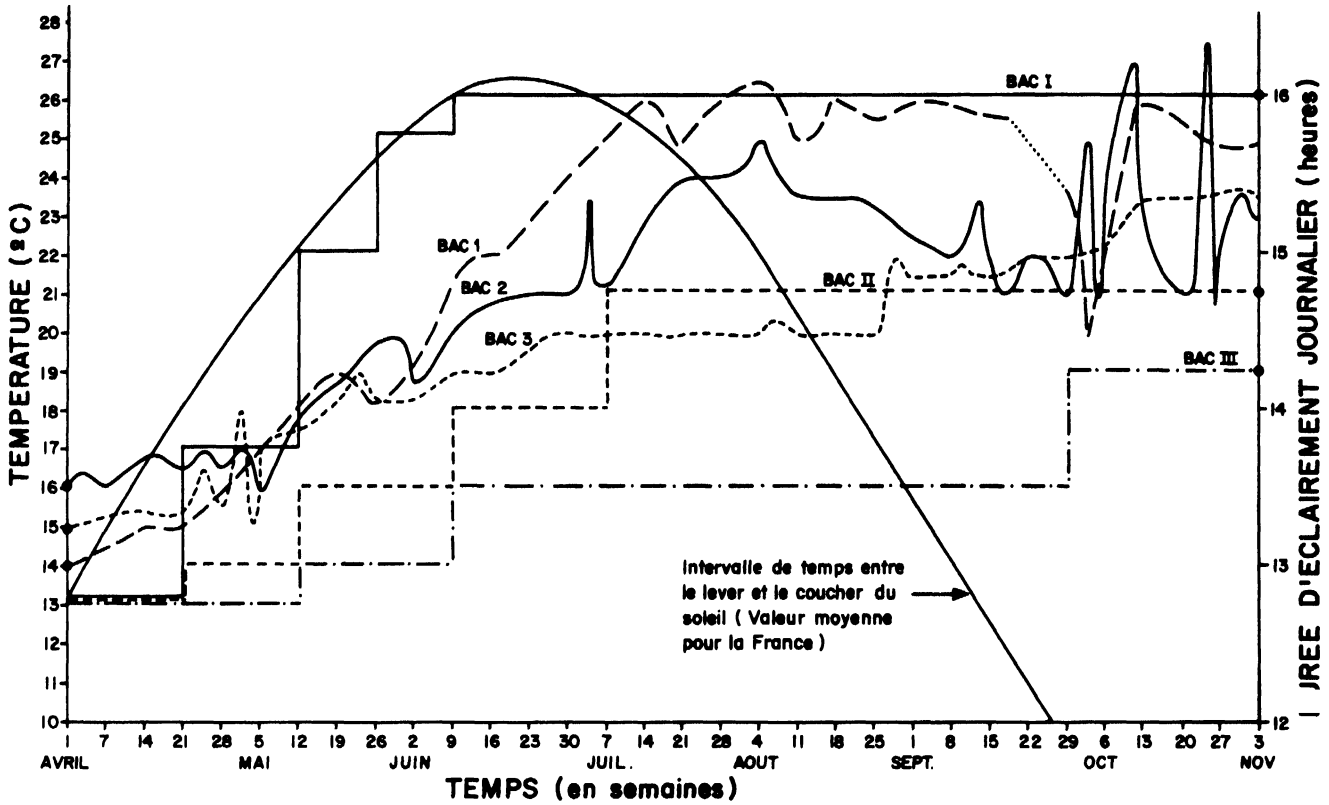


Fig 1. Variation de la durée d'éclairement journalier et de la température dans les trois bacs

total minimal. La collecte d'une ponte déterminée peut s'étaler sur plusieurs jours, comme le montrent les exemples ci-dessous:

(*i*) *Ponte No. 14 du bac 2 le 6 août 1975.* 6 août à 09.00 h—3 000 œufs; 6 août à 16.00 h—néant; 7 août à 09.00 h—14 000 nauplii III; 7 août à 16.00 h—850 nauplii IV; 8 août à 09.00 h—2 500 nauplii V; 8 août à 16.00 h—150 nauplii VI; 9 août à 09.00 h—350 zoés I, soit un total de 20 850.

(*ii*) *Ponte No. 19 du bac 2 le 4 septembre 1975.* 4 septembre à 09.00 h—5 500 œufs; 5 septembre à 09.00 h—40 000 nauplii III; 6 septembre à 09.00 h—7 000 nauplii V; 7 septembre à 09.00 h—200 zoés I, soit un total de 52 700.

Après récupération des larves dans le collecteur et ajustement de prélèvement à un volume de l'ordre de 200 à 500 ml, le comptage a été effectué sur un échantillon prélevé à la pipette après agitation (1/100ème à 1/50ème du volume total).

Au cours de la période du 10 juillet au 3 novembre (près de quatre mois), 41 pontes ont été observées dans le bac 2, 28 dans le bac 1, et 18 dans le bac 3 (9 de ces pontes sont postérieures à la remontée de la photopériode et de la température dans ce bac). Les pontes se poursuivaient encore le 10 novembre. Le nombre moyen d'œufs ou de larves par ponte pour chaque bac a été de 17 925 pour le bac 1, 18 149 pour le bac 2, et 4 800 pour le bac 3 (Tableau I). Les œufs obtenus ont toujours éclos à 100%, et les pontes mises en élevage pour la constitution de futurs lots de géniteurs se sont également bien développées. Ainsi, la première ponte du 10 juillet a fourni, dans des conditions d'improvisation assez éloignées des conditions optimales d'élevage larvaire, plus de 1 000 post larves avec un taux de survie de 18%; ces animaux pesaient entre 5,5 et 7,5 g de poids individuel 120 jours après l'éclosion.

3.3 *Pontes provoquées*

Selon la technique utilisée dans les écloseries commerciales japonaises pour obtenir la ponte des femelles sauvages, deux pontes supplémentaires ont été obtenues à la mi-septembre en isolant des femelles mûres de la classe 1973. La première ponte provient d'une femelle du bac 2 pesant 92 g. Placée dans un bac de 800 l porté à 29°C et à l'obscurité, cette femelle a pondu au cours de la première nuit suivant l'isolement 455 000 oeufs dont le taux d'éclosion a été supérieur à 98%. Une vingtaine de jours plus tard, une femelle de 90 g provenant du bac 1 a été isolée dans les mêmes conditions. Elle a fourni au cours des troisième et quatrième nuits suivant l'isolement (nuits du 12 au 13 et du 13 au 14 octobre) 80 000 puis 79 000 oeufs, soit un total de 159 000 oeufs.

La même méthode appliquée à quelques femelles de la classe 1974 n'a pas permis d'obtenir de pontes.

4 Conclusion

La ponte dans les conditions naturelles est inconnue chez *Penaeus japonicus*. Dans nos conditions d'élevage, la ponte est nettement séquentielle: dans le bac 2, 22 femelles (chiffre maximal puisque correspondant à la date du 10 juillet) ont fourni 42 pontes (y compris la ponte provoquée du 19 septembre), et si l'on en juge par l'état des femelles, ce chiffre est loin d'être définitif. En ce qui concerne le nombre d'œufs par ponte, les conditions écologiques imposées aux bacs 1 et 2 sont nettement supérieures à celles du bac 3; le bac 2 montre d'autre part une certaine précocité dans le total d'œufs obtenus. Enfin, toutes les pontes obtenues sont excellentes, alors que la technique japonaise pratiquée sur des femelles sauvages donne des taux d'éclosion de 40 à 60% seulement d'après Shigueno (1975), pourcentage biologiquement anormal.

TABLEAU I

NOMBRE D'ŒUFS OU DE LARVES RECUEILLIS PAR PONTE POUR CHAQUE BAC

Dates	BAC I		BAC II		BAC III	
	Ponte	*Nb indiv. récoltés*	*Ponte*	*Nb indiv. récoltés*	*Ponte*	*Nb indiv. récoltés*
10.VII			1ère	7 100		
14.VII	1ère	1 340	2ème	10 490		
15.VII			3ème	11 560	1ère	non dénb.
16.VII			4ème	11 150	2ème	non dénb.
18.VII	2ème	19 700				
19.VII	3ème	12 000	5ème	25 000		
20.VII			6ème	59 800		
24.VII	4ème	48 900	7ème	15 050		
25.VII			8ème	51 100	3ème	14 250
26.VII	5ème	46 950				
28.VII			9ème	24 970	4ème	8 070
29.VII	6ème	9 300				
30.VII			10ème	11 600	5ème	1 250
31.VII	7ème	8 870				
01.VIII			11ème	6 420		
02.VIII	8ème	10 250	12ème	30 920		
04.VIII					6ème	150
05.VIII			13ème	10 700		
06.VIII			14ème	20 850		
28.VIII	9ème	20 300				
30.VIII	10ème	3 000	15ème	10 500		
			16ème	11 500		
31.VIII			17ème	22 500		
02.IX			18ème	13 700		
03.IX	11ème	9 500				
04.IX	12ème	3 900	19ème	52 700		
10.IX			20ème	200		
12.IX					7ème	7 330
13.IX	13ème	4 930				
14.IX	14ème	37 000				
18.IX			21ème	11 500		
21.IX			22ème	10 600	8ème	800
22.IX			23ème	14 400		
23.IX	15ème	8 200	24ème	34 400	9ème	900
	16ème	11 400				
24.IX			25ème	29 300		
26.IX	17ème	1 000				
28.IX	18ème	13 300	26ème	600		
			27ème	100		
04.X			28ème	13 300		
07.X	19ème	750				
08.X	20ème	18 150				
12.X					10ème	3 750
13.X					11ème	3 500
14.X					12ème	5 600
15.X			29ème	19 200		
16.X	21ème	1 000	30ème	27 700		
17.X	22ème	6 700				
19.X			31ème	11 150	13ème	7 300
21.X			32ème	1 150		
22.X			33ème	9 500	14ème	1 600
25.X			34ème	2 000		
27.X	24ème	58 500	35ème	17 250		
28.X					15ème	4 350
29.X	25ème	35 800	36ème	8 400	16ème	4 650
			37ème	24 800		
30.X	26ème	14 200	38ème	79 750	17ème	1 400
31.X	27ème	83 000			18ème	11 900
01.XI			39ème	7 500		
02.XI			40ème	25 050		
03.XI	28ème	11 250	41ème	5 900		
Total	28	501 890	41	744 110	18	76 800

Le nombre total de larves obtenues (1 936 800 pour 60 femelles, soit 32 280 larves par femelle) est très faible par rapport aux données provenant de pontes provoquées (100 000 larves viables environ). Mais dans ce dernier cas, il s'agit de femelles de deux ans, le poids de 90 g étant considéré comme une limite inférieure (Shigueno, 1975).

L'aspect le plus important concerne la possibilité d'intervenir sur la période de ponte. Les animaux utilisés pour cette expérience se seraient reproduits à un an dans les conditions naturelles japonaises, soit au mois de mai, et au plus tard en juin-juillet. Or, les pontes se poursuivaient encore le 10 novembre, en particulier dans les bacs 1 et 2. Tout se passe comme si le maintien en conditions climatiques tropicales au-delà de la saison d'été conduisait à l'acquisition d'un comportement sexuel nouveau, avec reproduction toute l'année sans pic marqué. L'obtention de futurs reproducteurs nés en captivité à différentes périodes de l'été 1975 et la poursuite de l'expérience actuellement en cours doivent permettre de mieux comprendre l'importance relative de l'horloge interne et des facteurs écologiques externes sur la reproduction de *P. japonicus*.

S'ils sont confirmés, ces résultats paraissent susceptibles

d'intéressantes applications aux élevages expérimentaux actuellement poursuivis: en effet, et plus peut-être que dans d'autres zones, la réussite des élevages de *P. japonicus* en France passe par la disponibilité de post larves dès le début du réchauffement des eaux (avril-mai selon les régions).

5 Références

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Etude de la Maturation et la Ponte Chez *Penaeus japonicus* en Captivité

J.-L. Caubère, R. Lafon, F. René et C. Sales

Résumé

L'absence d'un stock naturel de géniteurs et la nécessité d'une reproduction précoce de post-larves, nous ont conduit à tenter d'obtenir puis de contrôler la reproduction chez *Penaeus japonicus*. Pour ce faire, en décembre 1973 quatre lots de 80 géniteurs (60 femelles et 20 mâles) d'un poids moyen de 15 g, provenant de notre élevage de post-larves de *P. japonicus* importées du Japon en mai 1973, ont été constitués. Ces quatre lots ont ensuite été soumis à des conditions accélérées de remontée photo- et thermopériodique. La maturation a pû être ainsi obtenue à plusieurs reprises de mars à octobre 1974. Cette maturation a abouti à une quinzaine de pontes, donnant près d'un million de nauplii (juin-juillet 1974 et septembre-octobre 1974). Les post-larves issues de ce cycle ont été mises en grossissement durant l'été 1974, jusqu'à un poids de 12 g le 30 septembre 1974. Le cycle sexuel a pû être suivi chez les femelles, grâce à l'analyse *in vivo* des géniteurs, à l'évolution du RGS, aux modifications macro- et microscopiques de gonades, aux variations des électrophorégrammes de l'hémolymphe et enfin aux pontes provoquées et naturelles des animaux.

Studies on the maturation and spawning of *Penaeus japonicus* in captivity

Abstract

The absence of a natural broodstock and the need for early reproduction of post-larvae have led us to obtain and then control reproduction of *Penaeus japonicus*. For this purpose, in December 1973 four batches of 80 broodstock (60 females and 20 males) weighing on an average 15 g were constituted from our culture of *P. japonicus* post-larvae imported from Japan in May 1973. These four batches were then exposed to accelerated increasing photo- and thermoperiods. It was possible in this way to obtain repeated maturation from March to October 1974. This maturation led to about 15 depositions of spawn, producing nearly one million nauplii (June-July 1974 and September-October 1974). The post-larvae from this cycle were fattened during the summer of 1974 up to a weight of 12 g on 30 September 1974. It has been possible to follow the sexual cycle of the females thanks to the *in vivo* analysis of the broodstock, evolution of the ratio of gonad size to body size, the macro- and microscopic changes in the gonads, the variations of the electrophoregrams of the haemolymph and finally to the induced and natural spawning of the animals.

Estudios sobre la maduración y desove de *Penaeus japonicus* en cautividad

Extracto

La ausencia de una población natural de progenitores y la necesidad de obtener la reproducción precoz de formas postlarvales nos movió a intentar primero conseguir y luego controlar la reproducción de *Penaeus japonicus*. Para ello se constituyeron en diciembre de 1973 cuatro grupos de 80 progenitores (60 hembras y 20 machos) de 15 g de peso medio, provenientes de nuestro criadero de formas postlarvales de *P. japonicus* importadas del Japón en mayo de 1973. Se sometió a esos cuatro grupos a un aumento del fotoperíodo y el termoperíodo, consiguiendo hacerlos madurar en varias ocasiones entre marzo y octubre de 1974. Se lograron unas quince puestas, con cerca de un millón de nauplii (junio-julio 1974 y septiembre-octubre 1974). Las formas postlarvales procedentes de ese ciclo se pusieron en engorde durante el verano de 1974, hasta alcanzar un peso de 12 g el 30 de septiembre de 1974. Se ha podido seguir el ciclo sexual de las hembras gracias al análisis *in vivo* de los progenitores, la evolución del RGS (relación peso de las gónadas al peso total del animal), las modificaciones macroscópicas y microscópicas de las gónadas, las variaciones de los electroforegramas de la hemolinfa y, finalmente la puesta inducida y natural de los animales.

1 Introduction

Depuis 1942, quand Fujinaga maîtrisa la ponte et la survie larvaire chez *Penaeus japonicus* de nombreuses productions de post-larves de pénaeides ont été réalisées dans le monde, ceci tant à l'échelle du laboratoire qu'à l'échelle industrielle (production japonaise 1972: 140 millions de post-larves).

Toutefois, à notre connaissance, les géniteurs femelles sont presque toujours pêchés mûrs dans le milieu quelques heures avant la ponte. (Hudinaga 1942; Fujinaga [Hudinaga], 1969; Yatsuyanagi et Maekawa, 1955; Kubo, 1956). Seul Hudinaga par communication orale dit avoir obtenu le cycle complet dans ses bassins d'élevages.

L'absence en France, de souche naturelle de pénaeide, rend primordiale pour développer cet élevage l'obtention régulière de la maturation et de la ponte des individus en élevage.

Le but de l'expérience, à l'échelle d'une exploitation de terrain est: obtenir la maturation chez des crevettes en élevage, étudier l'influence du photopériodisme et du thermopériodisme sur cette maturation, et avancer sous nos climats la maturité de juin-août à avril-juin, ce qui permettrait d'exploiter pleinement la saison estivale de croissance.

2 Matériel et méthodes

Le 10 juin 1973, 125 000 post-larves de *P. japonicus* en provenance du Japon ont été mises en élevage à Maguelone (Hérault) sur les bords de la Méditerranée. Le bassin d'élevage de 5 000 m^2 de surface et de 1,30 m de profondeur est placé en bordure de mer et alimenté par celle-ci. Nourries à l'aide de *Carcinus mediterraneensis* broyés, les pénaeides avaient un poids moyen de 13 g quatre mois et demi plus tard.

Le 15 décembre 1973, 320 animaux ont été mis en expérimentation dans 4 bassins circulaires, protégés des intempéries par une serre plastique. Les caractéristiques des bassins sont les suivantes: diamètre—5 m; hauteur—1,20 m; capacité—22 m^3. La Fig. 1 en montre la structure. A cette date on a mis dans chaque bac 2 lots de crevettes: 80 géniteurs âgés de 7 mois, dont 60 femelles et 20 mâles provenant de l'élevage précédemment cité (poids moyen 15 g), 9 géniteurs âgés de 18 mois dont 3 femelles et 6 mâles provenant du même élevage, et ayant hiverné dans un bassin extérieur (poids moyen 55 g). Le renouvellement des eaux est assuré par de l'eau pompée en mer à raison de 200 l/h, soit en 5 jours la capacité du bac. Un recyclage de l'eau dans le bac est assuré par des 'air lift' drainant un filtre au fond du bassin (Fig. 1); ce recyclage est d'environ 10 m^3/h. La thermorégulation est réalisée par thermoplongeur électrique de 4 kW, contrôlé par thermostat

d'aquarium. La photorégulation est assurée d'une part par la lumière naturelle, d'autre part par un groupe de 4 tubes au néon COOLWHITE 65 W par bac, programmé par une horloge à contact et éclairant avec une intensité de 4 000 lux la surface du bassin.

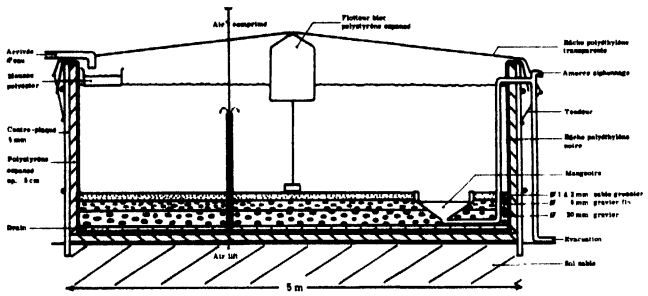


Fig 1. Structure des bacs de maturation

Durant toute l'expérience, l'alimentation a été constituée d'un mélange de *C. mediterraneensis* broyés et de moules *Mytilus galloprovincialis* ouvertes. Cette nourriture était distribuée à satiété chaque jour à 17 h. Le lendemain à 8 h, les reliefs étaient prélevés et le taux de nutrition évalué. Le taux de ration humide est ici le quotient du poids humide de nourriture ingérée par le poids total des animaux échantillons chaque semaine.

Le schéma de l'expérience combine en quatre bassins (Tableau I) d'une part deux remontées photopériodiques de 8 lux à 16 lux (l'une naturelle sur 6 mois; l'autre accélérée sur 3 mois) et d'autre part deux remontées thermiques de 15 à 24°C (l'une normale sur 6 mois; l'autre accélérée sur 3 mois). Les autres facteurs du milieu ont été maintenus identiques dans les quatre bassins. Les paramètres suivis ont été: température, salinité, taux d'oxygène dissous, pH, taux de nutrition et taux de mortalité. Chaque quinzaine, 2 femelles par bassin ont été prélevées afin de suivre l'évolution des gonades.

TABLEAU I
SCHEMA D'EXPERIMENTATION

Remontée thermopériodique \ *Remontée photopériodique*	*Accélérée de 6 à 3 mois*	*Naturelle*
Accélérée de 6 à 3 mois	Bassin 1 (B1)	Bassin 3 (B3)
Naturelle	Bassin 2 (B2)	Bassin 4 (B4–témoin)

L'étude de la vitellogenèse a été réalisée de façon concomitante par quatre voies se complétant mutellement:

(*i*) Etude macroscopique *in vivo* par vision à contrejour. La transparence des animaux permet à certains stades de voir les gonades des femelles se détacher en sombre sur le reste des organes (Fig. 2). On peut ainsi apprécier la turgescence des ovaires et leur couleur.

(*ii*) Etude macroscopique après dissection des ovaires, appréciation de la couleur, de la texture et du rapport gonado-somatique comme suit:

$$\text{RGS} = \frac{\text{poids des gonades} \times 100}{\text{poids total de l'animal}}$$

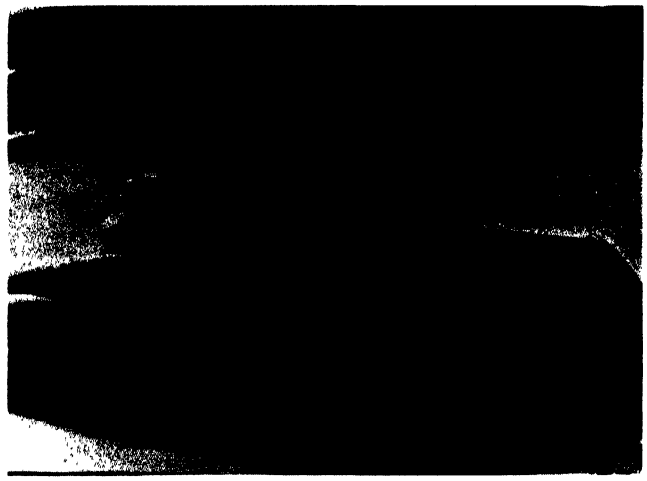


Fig 2. Analyse par contre-jour d'un géniteur pénaeide femelle au 11.03. Les gonades, R G S 8, apparaissent nettement par contre-jour en une bande sombre

(*iii*) Etude microscopique des gonades par MM. Bourguet et Exbrayat, laboratoire du professeur Vernet, Faculté des Sciences de Montpellier.

(*iv*) Etude de l'évolution des électrophorégrammes de l'hémolymphe des géniteurs réalisée par M. Acier, laboratoire du professeur Trille, Faculté des Sciences de Montpellier. Ils ont été pratiqués à partir de l'hémolymphe prélevée *in vivo* sur un gel de polycrylamide à 6,5% de monomères totaux après coloration à l'amidoschwarz 10B. En première analyse tous les électrophorégrammes quel que soit le stade de maturité, présentent deux facies caractéristiques. Ceci permet de les classer en deux groupes: groupe I électrophorégramme en bande nette et individualisée, groupe II électrophorégramme comportant dans la partie centrale une migration en forme de cône. Durant le cycle sexuel, seuls les électrophorégrammes du groupe I présentent des modifications significatives. Nous avons donc étudié essentiellement ceux du groupe I.

Enfin lorsque la maturité a paru suffisante, les pontes provoquées ou naturelles constituent un critère indiscutable. Nous avons tenté de provoquer la ponte à l'aide de chocs thermiques, de chocs de pression, ainsi que par leur association.

3 Résultats

Les paramètres physico-chimiques du milieu d'élevage ont été maintenus pendant toute la durée de l'expérience dans les limites suivantes: pH 7,5–8,5; salinité 30,5–36‰; O_2 dissous 50–130% de saturation. Les thermopériodes et photopériodes prévues ont été respectées avec une variabilité de ± 2°C pour la température (Fig. 3), ± 5 mn pour la photopériode. Le taux de nutrition a été évalué dans les différents bacs: il varie de 10 à 70%. Enfin, la mortalité durant les 4 mois d'expérience n'a pas excédé 5%, essentiellement groupée dans les 8 jours suivant la mise en bassin.

Le 14 janvier 1974 (J + 30), les ovaires n'étaient pas visibles en contre-jour sur l'animal. A ce stade, l'analyse microscopique des ovaires disséqués ne montrait aucune différence entre les 4 bassins; le RGS s'étageant de 0,5 à 0,1. Les ovaires étaient blancs, translucides, filiformes (Fig. 4). L'analyse microscopique a montré des ovocytes de petite taille, diamètre 20–40 μ (Fig. 5). Les électro-

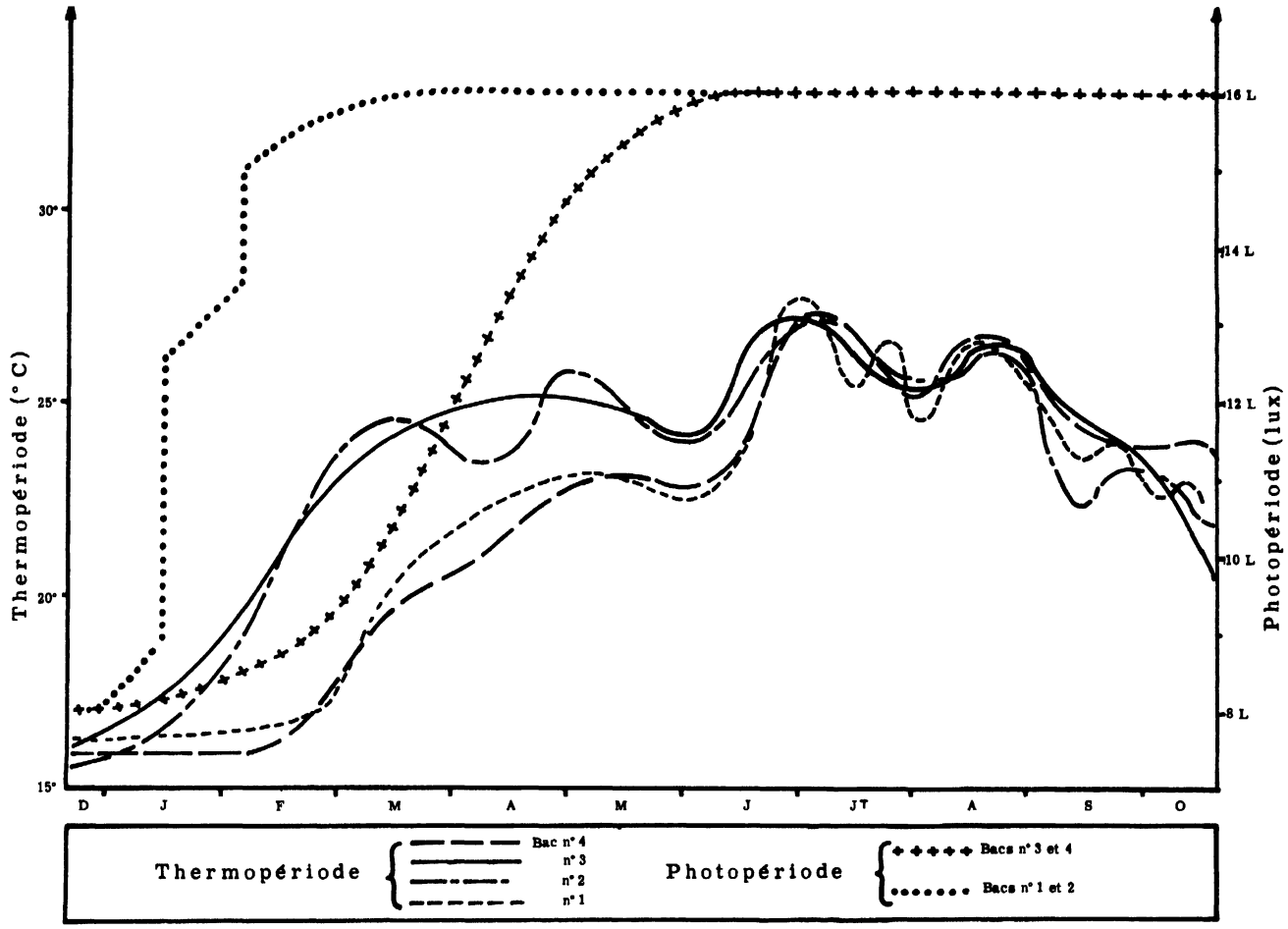


Fig 3. Evolution des photoperiodes et de thermoperiodes auxquelles sont soumis les lots B1, B2, B3, B4 durant l'experimentation

phorégrammes de l'hémolymphe des animaux prélevés présentaient tous une bande centrale unique (Fig. 6, tube 1).

Le 1er février 1974 (J + 45), aucune variation significative n'a été enregistrée entre les prélèvements des B1, B2, B3, B4. Les RGS variaient autour de 1. Les électrophorégrammes présentaient toujours une bande centrale unique (Fig. 6, tube 2).

Le 18 février 1974 (J + 61), les dissections ont mis en évidence une évolution de la taille des gonades, dans les lots B1 et B4. Leurs RGS étaient respectivement 1,9 et 1,8, leur coloration blanc opaque tacheté d'orange. Les lots 2 et 3 présentaient toujours des RGS voisins de 1. Rien n'était visible sur des animaux vivants. Une analyse microscopique a montré les ovocytes immatures. Les électrophorégrammes de l'hémolymphe des géniteurs femelles prélevés dans B1, B2, B3, B4 étaient identiques et présentaient tous une bande centrale unique.



Fig 4. Ovaire après dissection, le2.02, Bac B1 R G S O, Stade I



Fig 5. Coupe microscopique d'ovaire G40 14.01 R G S O, 6 Bac B1 Stade I, ovocyte diamètre 20 a 40 u

Le 5 mars 1974 (J + 78), les nouveaux prélèvements ont montré de manière évidente l'évolution des animaux de B1. Les gonades étaient alors bien visibles sur les animaux vivants. A contre-jour, elles se détachaient au niveau de l'abdomen en une bande sombre (Fig. 2). Au niveau de céphalothorax, des lobes orangé clair tranchaient sur l'hépatopancréas et sur les flancs du moulinet gastrique. A

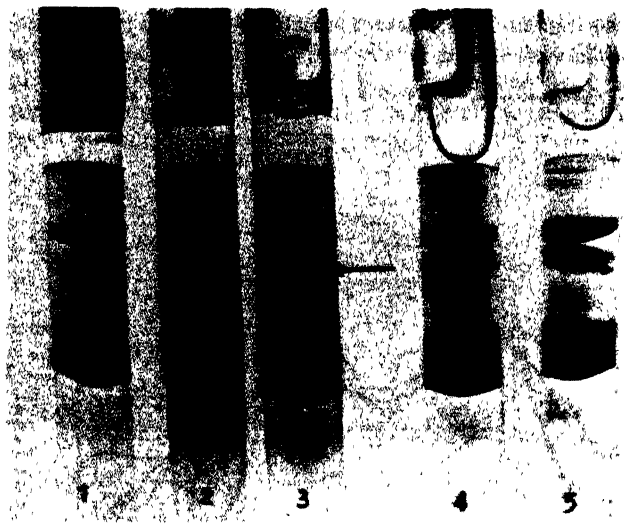


Fig 6. Electrophorégrammes d'hémolymphe de géniteurs femelles. Electrophorégrammes de l'hémolymphe aux stades I, II, III, IV, V

ce stade les géniteurs femelles sont imprégnés (présence des spermatèques sur le thelycum de la femelle). A la dissection, les ovaires apparaissaient maintenant bien développés; ils étaient devenus opaques et leur coloration générale était orange. Le RGS était d'environ 4 (Fig. 7); aucune variation notable n'était enregistrée dans les autres bacs. A ce stade l'étude microscopique a montré que l'accroissement du RGS est essentiellement dû à l'augmentation du pourcentage d'ovocytes matures diamètre 210–230 μ. Pour ce qui est des B2, B3, B4, les RGS étaient respectivement: 1,1; 0,9; 1,7. Les électrophorégrammes de l'hémolymphe des géniteurs femelles prélevés dans les B2, B3, B4 restaient sans changement. Seul l'électrophorégramme de l'hémolymphe des prélèvements du B1 présentait une bande centrale double (Fig. 6, tube 3). Analysée en bidimensionel (reprise sur gel d'acrylamide de la portion incriminée d'un électrophorégramme sur cellogel) et colorée au noir Soudan (mise en évidence des lipoprotéines) il apparaît que cette deuxième bande correspond à une lipoprotéine. L'électrophorèse d'un broyat d'ovaire mature présente en abondance cette bande lipoprotéique. On peut donc penser que cette lipoprotéine est intimement liée à la maturation.

Le 11 mars 1974 (J + 84), le prélèvement sur B1 a montré des ovaires plus turgescents et plus sombres que précédemment, le céphalothorax était largement envahi par les lobes antérieurs des gonades qui présentaient alors une couleur vert olive. A la dissection (Fig. 8) les ovaires étaient très développés, surtout dans la partie centrale; ils paraissaient vert sombre. Le RGS était alors de 8. L'analyse microscopique a montré des ovocytes apparemment mûrs, diamètre 230–250 μ (Fig. 9). Sur les lots B2, B3, B4, aucune variation significative n'a été enregistrée, les RGS étant respectivement de 1,3; 1,2 et 1,9. L'électrophorégramme des femelles du lot B1 a montré la disparition de la lipoprotéine précédemment mise en évidence, ce qui peut être interprété comme la fin de la maturation, la lipoprotéine étant à ce stade stockée dans l'ovaire (Fig. 6, tube 4). Ce fait est en accord avec les résultats obtenus sur: *Penaeus kerathurus* (Ceccaldi, 1970, 1971); *Palaemon adspersus* (Arcier, 1973).

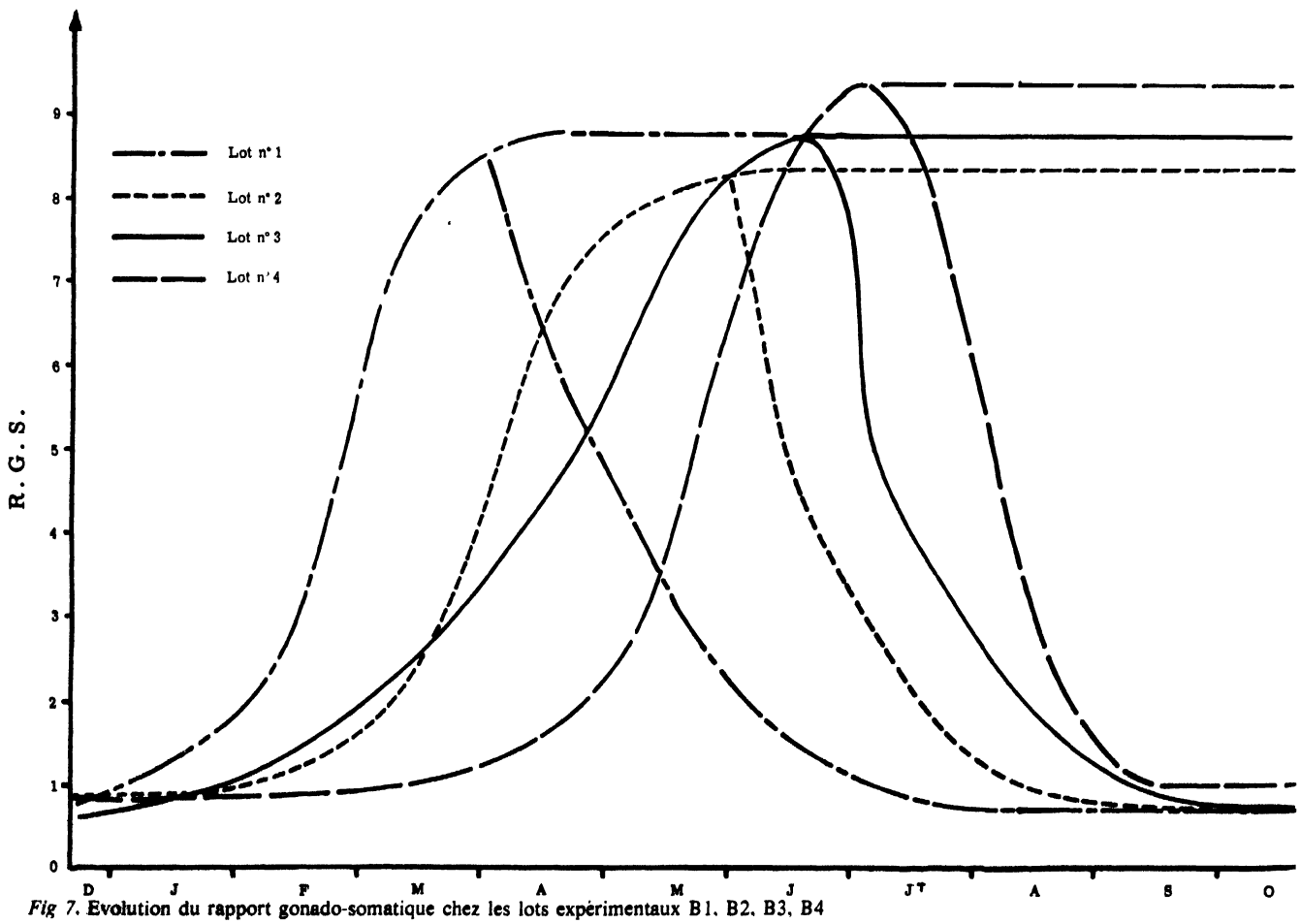


Fig 7. Evolution du rapport gonado-somatique chez les lots expérimentaux B1, B2, B3, B4



Fig 8. Ovaire après dissection: (11 mars – Bassin B1) R G S 8. Stade IV



Fig 9. Coups microscopique d'ovaire: (11 mars – Bassin B1) R G S 8 Stade IV ovocyte diametre 220 à 240 u

Le 19 mars 1974 (J + 92) de nouveaux prélèvements ne montraient pas d'évolution très significative des animaux. Les ovaires de l'animal prélevé dans B1 étaient turgescents et présentaient plusieurs renflements dans la partie antéro-abdominale (RGS très voisin de 6).

Le 4 avril 1974 (J + 108), l'état de maturité ne semblait pas avoir varié dans B1. Par contre, une évolution était sensible dans B2 et B4; les crevettes femelles de ces bacs avaient des ovaires nettement visibles par transparence à l'œil nu. Après dissection l'ovaire apparaissait coloré en jaune légèrement orangé. Les RGS étaient entre 3 à 4 (3,2 à 3,8). A ce stade les géniteurs femelles sont imprégnés.

Le 20 avril 1974 (J + 124), le stade d'évolution gonadique des animaux du B1 (appréciation faite *in vivo* de la taille des ovaires), s'étalait sur une large gamme allant de l'ovaire très large et turgescent à l'ovaire invisible. La coloration des ovaires bien développés était généralement beige-brunâtre. Certains parmi les plus mûrs restaient vert sombre. Deux individus prélevés ont montré après dissection un RGS de 5 et 9. Dans B2 et B4, l'évolution déjà constatée le 4 avril 1974, s'est poursuivie aboutissant à une maturité apparente de l'ensemble des 2 lots: RGS: B2 6 et 7, B4 5 et 6. Les couleurs allaient de vert pré à vert olive. Le B3 ne montrait pas de variation très significative. RGS: B3 1,7 et 1,5 (ovaires blancs).

Le 20 mai 1974 (J + 154), la dispersion des stades de maturité s'est poursuivie sur B1 et était largement amorcée sur B2 et B4. B3 suivait avec 1,5 mois de retard B2 (RGS 3 et 4). Aussi les géniteurs femelles de B3 étaient-ils imprégnés à cette date.

Le 4 juin 1974 (J + 184), on a constaté une large dispersion des stades de maturité dans B1, B2 et B4 tandis que B3 arrivait à maturité (RGS 7 et 8). A partir du 9 juin 1974 (J + 189) une série de tentatives de ponte fut entreprise à l'aide de chocs de pression associés à des chocs thermiques.

Du 6 au 10 juin 1974, une descente thermique de 2°C par rapport aux moyennes maintenues à cette époque dans les bacs a été appliquée aux 4 lots.

Le 10 juin 1974 à 23 h, 4 géniteurs femelles de B4 furent placés sous atmosphère d'oxygène pur, dans un caisson pressurisé à 2,5 kg/cm^2, en choc thermique négatif $\Delta t = -2°C$. Les caractéristiques de l'eau du caisson étaient les suivantes: température 20°C, salinité 37‰, pH 8,2. Dix heures plus tard, le 11 juin 1974, le caisson a été ouvert après une dépressurisation étagée sur 15 mn. On a constaté qu'un seul géniteur a pondu: 100 000 œufs. A 15 h, 10 000 de ces œufs placés depuis 11 h dans un bac de 600 l à 18°C ont donné naissance à des nauplii vaiables. Les installations dont nous disposions n'étant pas prévues pour faire de l'élevage larvaire, seul un petit nombre de nauplii furent élevés au-delà de 24 h. Ainsi au 30 septembre 1974, les jeunes *P. japonicus* nés le 15 juin 1974, pesaient 5–9 g en moyenne, les plus gros atteignant 12 g (Fig. 10). Cette expérience fût renouvelée 48 h plus tard. Le 12 juin 1974, 4 femelles de B1, dont 1 âgée de 25 mois et pesant 87 g, furent placées dans les mêmes conditions que les précédentes; 10 h plus tard, l'ouverture du caisson permit de constater que seule la femelle de 25 mois avait pondu. Cette ponte était de 250 000 œufs viables. Les essais de pressurisation des géniteurs furent entrepris systématiquement, leurs caractéristiques et leurs résultats sont présentés dans le Tableau II. Seize expériences de pressurisation ont été tentées du 10 juin au 3 octobre 1974, portant au total sur 74 géniteurs femelles des lots B1, B2, B3, B4 pesant de 34 à 75 g. Les températures des bacs de prélèvement s'étageant de 23,5 à 28,3°C, les températures d'expérimentation variant de 20 à 22°C la salinité de 37,2 à 39,2‰, le pH de 7,5 à 8,5. Au cours de ces manipulations on obtient 6 pontes de: 100 000 œufs le 10 juin, 250 000 œufs le 12 juin, 100 000 œufs le 11 juillet, 300 000 œufs (2 pontes) le 25 septembre, 100 000 œufs le 3 octobre, respectivement. Les taux d'éclosions viables évalués par le taux de survie à 24 h ont été respectivement de 10, 40, 0, 90, 90%.

Parallèlement, dès la première ponte provoquée on constatait des pontes spontanées dans l'ensemble des bacs. En



Fig 10. Géniteurs et leurs enfants au 20/9/74 Naissance le 15/6/74

ce qui concerne leur importance et leur fréquence on pouvait relever à chaque fois des différences significatives au niveau des 4 bacs que l'on pouvait classer en 2 groupes: les bacs à fortes pontes B1 et B4 (1–5 nauplii par litre), les bacs à faibles pontes B2 et B3 (1–5 nauplii par 10 litres). Les caractéristiques des diverses pontes sont rapportées dans le Tableau II.

Le 24 juin 1974 (J + 200), l'ensemble des lots présentait des animaux matures, ce qui confirme les pontes obtenues à cette période. Les prélèvements ont donné les RGS suivants: B1 6,2 et 1,8; B2 5 et 7,1; B3 8,1 et 1,5; B4 9 et 6.

Le 10 juillet 1974 (J + 215), la dispersion des stades de maturité était évidente dans tous les bassins. Les prélèvements ont donné les RGS suivants: B1 5,3 et 1,5; B2 6 et 3; B3 6,1 et 0,5; B4 6,1 et 4.

Le 25 juillet 1974 (J + 225), la situation était restée stable dans les quatre lots, qui contenaient toujours des animaux aux ovaires très développés: RGS: B1 6,5 et 3; B2 9 et 1,2; B3 5,3 et 4,1; B4 3,3 et 6.

Le 15 août 1974 (J + 236), les prélèvements ont confirmé la situation précédente, RGS: B1 4,2 et 3,3; B2 5 et 0,6; B3 8,5 et 4, B4 2,3 et 1,2.

Le 5 septembre 1974 (J + 267), 2 nouvelles pontes provoquées par choc de pression ont été obtenues, sur 2 géniteurs femelles provenant des lots B3 et B1. Ces pontes nous ont permis de récolter 300 000 œufs ayant un taux d'éclosion de 90% (Tableau II). Les prélèvements ont donné les RGS suivants: B1 5,3 et 3,5; B2 6,3 et 2,5; B3 7 et 4; B4 3,5 et 1,5.

Le 25 septembre 1974 (J + 287), les prélèvements ont confirmé la situation précédente, RGS: B1 7,2 et 0,8; B2 3,2 et 0,5; B3 7,5 et 3,5; B4 5,2 et 3.

Le 3 octobre 1974 (J + 294), une nouvelle ponte de 100 000 œufs a été obtenue par pressurisation d'une femelle de 58 g du lot B4. Depuis cette date, nos installations ne nous permettant pas de maintenir la température de 24°C désirée dans les bassins, l'expérience fut arrêtée.

Pour confirmer ces résultats, une nouvelle expérimentation fut entreprise dans les mêmes bassins au début décembre 1974. Elle permit d'obtenir sur ces mêmes géniteurs la maturité dès la mi-mars 1975, confirmée par plusieurs pontes au début avril 1975, toutes non viables. D'autres pontes, viables celles-ci, furent obtenues en juin 1975. Cette nouvelle expérimentation connut plusieurs incidents matériels indépendants de notre volonté.

4 Discussion

4.1 *Matériel technique*

On peut penser que la faible mortalité enregistrée, la bonne croissance obtenue, ainsi que l'évolution vers la maturité sexuelle des géniteurs ont été favorisée par: le bon contrôle des caractéristiques physico-chimiques d'élevage (notamment, stabilité du pH, de l'O_2 dissous), un volume unitaire

TABLEAU II
PONTES OBTENUES

(*a*) Pontes naturelles

Date	*Température (°C)*				*Nombre de nauplii à 24 h de survie*			
	B1	*B2*	*B3*	*B4*	*B1*	*B2*	*B3*	*B4*
10 juin	24,0	22,9	22,9	24,4	60 000	10 000	5 000	40 000
11 juin	24,5	23,2	22,5	24,5		5 000		20 000
12 juin	26,0	24,2	24,6	26,8			12 000	30 000
13 juin	28,4	26,7	24,6	27,2				
14 juin	29,8	27,2	27,9	29,9				50 000
15 juin	28,0	27,7	28,3	30,2	120 000			
16 juin	26,2	27,0	27,4		150 000			
17 juin	28,6	27,0	27,4					
18 juin	29,1	27,4	27,6		30 000			
19 juin	29,2	27,9	27,7					
20 juin	28,2	27,7	27,8			5 000		
21 juin	28,3	27,8	27,7				8 000	
22 juin	28,2	27,0	27,9		10 000			

(*b*) Pontes déclenchées par pressurisation

Date (heure)	*Bac de prélèvement*	*Poids des animaux prélevés (g)*	*Température des bacs de prélèvement (°C)*	*Pressurisation*		*Température d'expériment (°C)*	*Résultats (oeufs)*	*Survie à 24 h (%)*
				Durée (h)	*Pression (Bar)*			
10 juin (22.30)	B4	42	23,8	12	2,5	20		
		39						
		41						
		45					100 000	10
12 juin (22.00)	B1	43	23,5	12	2,5	20		
		39						
		44						
		75					250 000	40
11 juill.	B2	48	28,1	12	2,5	22		
		50						
	B3	51	28,3				100 000	1
		49						
5 sept.	B1	48	23,8	12	2,5	28		
	B2	55	23,5				300 000	90
	B3	53	24,0					
	B4	51	24,2					
3 oct.	B1	58	22,5	12	2,5	28		
	B2	54	23,5					
	B3	65	22,5					
	B4	60	23,0				100 000	90

de travail important (22 000 l) et une alimentation qui semble adéquate.

4.2 *Conclusions*

Durant l'évolution vers la maturation, on peut constater qu'une assez bonne corrélation s'établit entre les 4 premières voies choisies pour analyser la maturité, c'est-à dire: étude macroscopique *in vivo* des gonades, étude macroscopique des gonades après dissection, évaluation du rapport gonado-somatique (RGS), étude microscopique des ovaires, et une étude des lipoprotéines de l'hémolymphe. Le 5éme critère, la ponte, semble n'être que partiellement concordant avec les autres comme le prouvent les résultats obtenus. Dans cette évolution, nous pouvons mettre en évidence cinq phases caractéristiques (Fig. 11):

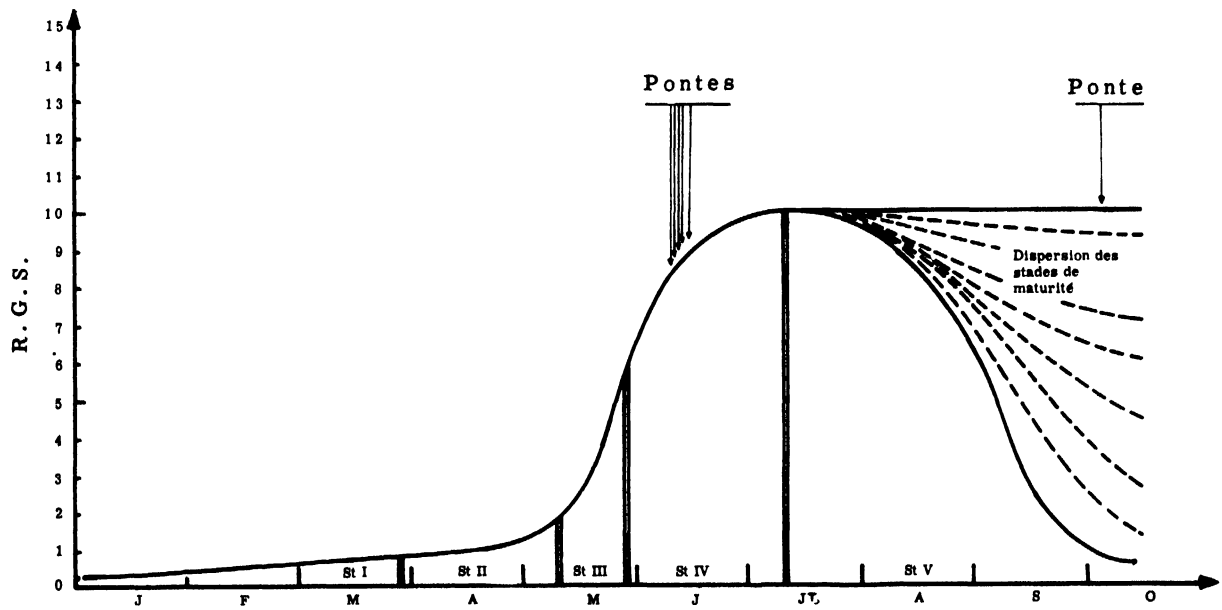
Au *stade I*, l'ovaire, invisible *in vivo*, a un aspect filiforme à la dissection, sa couleur est blanc translucide. La lipoprotéine caractéristique n'est pas décelable à l'électrophorèse. Le RGS se situe autour de 1. A l'analyse microscopique, l'ovaire est en prévitellogénèse, ovocytes, diamètre 18–40 μ, noyaux des ovocytes 10–20 μ (Fig. 5). La durée de cette phase est variable suivant les expériences (1 mois à 3,5 mois) (Fig. 11).

Au *stade II*, l'ovaire toujours invisible *in vivo* apparaît plus épais que précédemment à la dissection, sa couleur est blanc opaque tacheté orange. La lipoprotéine caractéristique n'est toujours pas décelable à l'électrophorèse, le RGS se situe entre 1 et 2,5. A l'analyse microscopique l'ovaire reste en prévitellogénèse, ovocytes diamètre 40–80 μ, noyaux des ovocytes 20–30 μ. La durée de cette phase est sensiblement 1–1,5 mois dans les différentes expériences précédentes.

Le *stade III*, est caractérisé par sa brièveté (8–15 jours). L'ovaire visible *in vivo* à contre-jour apparaît jaune orangé à orange vif. A la dissection les lobes antérieurs de l'ovaire recouvrent l'hépatopancréas. La lipoprotéine caractéristique est maintenant mise en évidence par l'électrophorèse. Le RGS se situe entre 2,5 et 6. A l'analyse microscopique, l'ovaire est en vitellogénèse. Dès le début de cette phase quelques ovocytes de taille mature diamètre 210–230 μ, noyau 60–80 μ, sont visibles dans l'ovaire; plus le RGS croît, plus le pourcentage des ovocytes matures croît. En fait les autres ovocytes ont dans leur grande majorité une taille se situant entre 80 et 120 μ, noyau 30–50 μ. Le très faible nombre d'ovocytes de taille intermédiaire diamètre 120–200 μ constaté à ce stade dans l'ovaire témoigne de la fugacité de cette étape de la maturation ovocytaire; ceci, dans nos conditions expérimentales. Cette évolution asynchrone des ovocytes vers la maturité, explique assez bien que des pontes partielles puissent être obtenues dès ce stade.

Le *stade IV* correspond à la maturité groupée du stock. L'ovaire visible *in vivo* (Fig. 2) apparaît vert sombre, très turgescent il a complètement envahi le céphalothorax et présente plusieurs renflements latéraux symétriques, dans la partie antéro-abdominale. A la dissection l'ovaire apparaît granuleux et vert sombre (Fig. 8). La protéine caractéristique n'est plus décelable à l'électrophorèse. Le RGS est supérieur à 7. L'analyse microscopique montre un fort pourcentage d'ovocytes de taille mature: diamètre 210–230 μ noyau 60–80 μ (Fig. 9). Cette phase dure 1–1,5 mois, suivant les expériences.

Enfin, le *stade V*, est caractérisée par une dispersion des stades de maturité chez les différents animaux. Le RGS varie de 8 à 1. L'ovaire souvent visible *in vivo* apparaît de brun sombre à beige clair et parfois vert bronze après dissection. La lipoprotéine caractéristique est de nouveau souvent décelable à l'électrophorèse (Fig. 6, tube 5), et dans certains prélèvements de nombreux ovocytes sont en



Analyse macroscopique in-vivo	Ovaires invisibles in-vivo			Ovaires visibles in-vivo	
Coloration des ovaires après dissection	Bleu translucide	Blanc\Tacheté opaque\rouge	Orange	Vert sombre	Variant de vert sombre à brun clair
Lipoprotéine caractéristique	Absente		Présente	Absente	Présente ou absente
Etat microscopique des ovaires	Prévitellogenèse		Vitellogenèse	Ovocyte taille mature	Ovocyte à divers stades de maturité

Fig 11. Liaisons entre les différentes voies choisie pour l'étude de la maturité: visibilité des gonades par transparence in vivo; coloration des ovaires après dissection; présence ou absence de la bande caractéristique dans l'électrophorégramme de l'hémolymphe; état des ovocytes à l'analyse microscopique; évolution du rapport gonado-somatique (R G S); pontes

dégénérescence diamètre 50 μ. Il existe toujours une certaine proportion (10 à 30%) d'animaux matures.

Dans cette expérience, l'évolution de la coloration des ovaires s'accorde avec les résultats obtenus sur d'autres espèces de pénaeides (Brare et Patland, 1974). En ce qui concerne l'évolution des électrophorégrammes de l'hémolymphe, on peut penser que la lipoprotéine mise en évidence dans cette expérience est très liée aux lipovitellines dont elle serait une forme véhiculable par l'hémolymphe. Ces résultats sont similaires à ceux obtenus sur d'autres espèces de crustacés par les auteurs précédemment cités.

D'autre part, l'analyse de l'évolution du RGS dont nous venons de montrer la signification (Fig. 11), amène à deux constations:

(*i*) L'influence des facteurs photopériodiques et thermopériodiques et leur synergie, est mise en évidence chez *P. japonicus*. Ainsi la contraction de 6 à 3 mois de la montée photopériodique et thermopériodique sur le B1, se traduit par une avance de 3 mois de la maturité sexuelle apparente par rapport à celle du lot témoin. Lorsque seule la montée d'un de ces 2 facteurs est contractée (B2, B3), la maturité apparente des animaux a 1,5 mois d'avance par rapport au lot témoin.

(*ii*) L'évolution sexuelle du stock de géniteurs femelles se fait dans les quatre lots, suivant deux temps caractéristiques: Dans un premier temps, pour l'ensemble des femelles, les critères d'évolution gonadique évoluent de façon très groupée vers une maturité apparente (RGS 7 à 9, ovaires de couleur vert bronze, ovocyte de 210 à 230 μ). Le développement des ovaires est globalement exponentiel. Ce premier temps correspond dans les quatre lots à la phase de remontée photo- et thermopériodique. Dans un deuxième temps, lorsque le palier photopériodique (16 h-lux/jour) et thermopériodique (24°C) est atteint (du 20 mars au 15 octobre pour le Bac B1, du 1 mai au 15 octobre pour les Bacs B2 et B3, du 1 juin au 15 octobre pour le Bac B4), les femelles semblent poursuivre individuellement leur évolution ainsi que le montre la dispersion des stades de maturité, tant au niveau de la coloration, du RGS (Fig. 7) que de l'analyse microscopique. Ainsi durant ce deuxième temps, à tout moment une partie des géniteurs semble mature, le reste s'échelonne aux divers stades de l'évolution ovarienne. Cette maturité sexuelle apparente d'une partie des animaux est confirmée par plusieurs pontes viables, tant naturelles que provoquées, qui s'étagent dans les quatre bacs du 11 juin au 3 octobre.

On peut donc penser, que durant le premier temps les géniteurs femelles en expérience ont une évolution groupée vers la maturité à l'instar des géniteurs sauvages des zones tempérées chaudes (mer du Japon, mer de Chine) (Yatsuyanagi et Maekawa, 1955). Durant le deuxième temps les géniteurs femelles en expérience étalent leur stade de maturité à l'instar des géniteurs sauvages des zones tropicales (Aquacop, 1975).

Sous l'influence d'une photopériode et d'une thermopériode stables à niveau élevé, les lots de géniteurs de *P. japonicus* auraient donc acquis un comportement sexuel nouveau: maturation et ponte désaisonalisées. Ces résultats semblent intéressants à deux titres, d'une part ils permettent d'envisager un contrôle de la période de ponte chez *P. japonicus*; d'autre part l'obtention des reproductions en captivité ouvre la voie à l'amélioration de cette espèce par le biais de la sélection génétique et de l'hybridation.

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Cultivo Experimental de Estadios Larvales del Camarón Blanco *Penaeus schmitti* y del Camarón Acaramelado *Penaeus duorarum notialis* en Laboratorio

D. Pérez Pérez y M. Oliva Suárez

Extracto

Se determinaron criterios para la selección de hembras maduras y las técnicas para su traslado al laboratorio, lográndose más de un 85% de supervivencia. El 100% de las hembras escogidas de *Penaeus schmitti* y el 75% de *P. duorarum notialis* produjeron desoves viables.

La fecundidad de las tallas analizadas para ambas especies en promedio fue para *P. duorarum notialis* de 128 000 y para *P. schmitti* 169 000 huevos. Se hallaron ecuaciones de regresión para relacionar la fecundidad con el peso de los ejemplares.

Se estudiaron las condiciones en las cuales se efectuó el desove hallando el periodo diario en que éste se produjo. No se observó diferencia entre distintas épocas del año ni influencia de la iluminación o la temperatura ambiental sobre las horas del desove.

Se estudió la tolerancia a niveles extremos de salinidad mediante el cambio brusco o con un acondicionamiento paulatino. Se hicieron determinaciones sobre el rango de tolerancia a la salinidad para los huevos y los estadios de nauplio, protozoea I protozoea III y mysis III siendo éste mayor en bajas salinidades en *P. schmitti* y en altas en

P. duorarum notialis.

A la medida que los estadios larvales se suceden el rango de tolerancia aumenta. Se estudió la influencia que pueden ejercer la salinidad y la temperatura del agua sobre el tiempo de desarrollo de los huevos y estadios de nauplius de *P. schmitti* siendo éste considerable en las salinidades extremas. En temperaturas del agua de 28,5°C el desarrollo tiene lugar mucho más rápidamente que en las temperaturas de 25,5°C.

Experimental rearing of larval stages of the white shrimp *Penaeus schmitti* and the pink shrimp *Penaeus duorarum notialis* in the laboratory

Abstract

Criteria were determined for the selection of mature females and techniques developed for transferring them to the laboratory, with a survival rate of over 85%. All the selected females of *Penaeus schmitti* and 75% of the *P. duorarum notialis* produced viable spawn.

The fecundity of each species on the basis of size was determined, with *P. duorarum notialis* averaging 128 000 eggs and *P. schmitti* 169 000. Regression equations were derived for fecundity as a function of the weight of individuals.

The conditions under which spawning occurred were studied, and the daily period in which it took place was determined. No difference was observed in regard to seasons of the year or to the influence of light or ambient temperature on time of spawning.

A study was also made of tolerance to extreme levels of salinity arrived at abruptly and gradually. The range of tolerance to salinity was determined for eggs and the nauplius, protozoaea I, protozoaea III and mysis III stages, and found to be greater at low salinities for *P. schmitti* and at high salinities for *P. duorarum notialis*. The range of tolerance rises with each succeeding larval stage.

A study was made of the possible influence of water salinity and temperature on the growing time of the egg and nauplius stages of *P. schmitti;* this influence was found to be considerable at extreme salinities. Growth is much faster at a water temperature of 28·5°C than at 25·5°C.

Elevage expérimental en laboratoire de la crevette blanche *Penaeus schmitti* et de la crevette rose *Penaeus duorarum notialis* aux stades larvaires

Résumé

On a déterminé des critères de sélection de femelles matures ainsi que les techniques permettant leur transplantation en laboratoire avec un taux de survie excédant 85%. Cent pour cent des femelles de *Penaeus schmitti* et 75% des femelles de *P. duorarum notialis* sélectionnées ont produit des œufs viables.

L'examen des deux espèces a permis d'en déterminer la fécondité moyenne, à savoir 128 000 œufs pour *P. duorarum notialis* et 169 000 pour *P. schmitti*. On a calculé les équations de régression applicables à la corrélation entre la fécondité et le poids des specimens.

L'étude des conditions dans lesquelles s'effectuait la ponte a permis d'établir le moment où elle se produisait dans le cours de la journée. L'observation n'a révélé aucun écart entre différentes époques de l'année, et ni la lumière ni la température ambiante n'exerçaient une influence sur les heures de ponte.

On a étudié la tolérance des crevettes à des niveaux extrêmes de salinité moyenne modifiés par altérations soudaines ou par ajustements progressifs. Des déterminations de la gamme de tolérance à la salinité ont porte sur les œufs et les divers stades larvaires: nauplius, zoe I, zoe III et mysis III; cette gamme de tolérance était plus considérable aux faibles concentrations de salinité pour *P. schmitti* et aux fortes concentrations pour *P. duorarum notialis*.

A mesure que se succédaient les stades larvaires la gamme de tolérance augmentait. On a etudié l'influence que peuvent exercer la salinite et la température de l'eau sur la période de développement des œufs et des stades nauplius de *P. schmitti*, cette influence étant considérable aux salinités extrêmes. Lorsque la température de l'eau atteint 28,5°C, le développement est beaucoup plus rapide que lorsque cette température est de 25,5°C.

1 Introducción

En los últimos 40 años se han realizado distintas investigaciones tendientes a hacer posible el cultivo de camarones marinos, siendo el género *Penaeus* uno de los más estudiados. Se logró la producción masiva de algunos de ellos como por ejemplo el *P. japonicus* (Hudinaga, 1942; Hudinaga y Kittaka, 1967).

De las 9 especies de peneidos que pueden tener importancia comercial, presentes en aguas cubanas, sólo *P. duorarum* y *P. schmitti* se encuentran en cantidades apreciables formando la mayor parte de las capturas (Nikolić y Ruiz de Quevedo, 1971).

Ambas especies tienen una amplia distribución geográfica. Están presentes en las Antillas Mayores, en la plataforma continental del Golfo de Honduras, a lo largo de las costas del Mar Caribe y la costa Atlántica de Brasil o sea hasta 21°15'S *P. duorarum notialis* y hasta 28°29'S *P. schmitti* (Pérez Farfante, 1969).

Son pocos los trabajos experimentales de cultivo en laboratorio que aporten datos para poder valorar su factibilidad para un cultivo artificial. Toledo Pérez y Fabré (1972) hicieron estudios sobre estadios larvales y Pérez Pérez y Ros (1974) sobre estadios postlarvales de la especie *P. schmitti*. Tabb *et al.* (1972) lograron el cultivo experimental de estadios larvales de *P. duorarum duorarum*.

2 Materiales y métodos

Las hembras de ambas especies fueron capturadas en la Bahía de Cienfuegos (costa sur de Cuba) a 320 km de distancia del laboratorio.

La salinidad fue determinada por el método del sulfocianuro de Levy y la temperatura medida en °C cada 6 horas. Las salinidades supranormales se obtuvieron a partir de agua de mar mediante la evaporación por ebullición y las subnormales mediante adición de agua destilada. Para las experiencias con huevos y larvas, el agua de bajas salinidades fue también previamente esterilizada por ebullición.

Los resultados presentados para huevos y larvas, corresponden a 3 series de pruebas consistentes de original y réplica para cada una de ellos. Los ejemplares de cada serie se obtuvieron de hembras distintas.

El fitoplancton utilizado para la alimentación se obtuvo mediante el cultivo. Debido al pequeño volumen de líquido utilizado fue necesario, para las experiencias a distintas salinidades, con protozoea, proceder a centrifugar los cultivos a los efectos de no alterar la salinidad al introducir el alimento. La concentración de fitoplancton para protozoeas y mysis se mantuvo entre $(80 \pm 20) \times 10^6$ células por l^{-1}. A los mysis, además se les suministró como alimento nauplios de *Artemia salina* recién eclosionados en una concentración de 4 por ml.

3 Obtención de hembras maduras

3.1 *Captura*

Con un barco camaronero tipo sondero se arrastró entre 20 y 60 minutos. La duración de arrastre dependió de la abundancia de la captura puesto que cantidades grandes acumuladas en el copo, dañan a los animales capturados.

3.2 *Selección*

Una vez depositada la captura sobre la cubierta, fue necesario proceder a escoger los ejemplares en un tiempo no mayor de 10 minutos. No resultó difícil reconocer las hembras maduras ya que presentaron una coloración característica debido al oscurecimiento de las gónadas que ocupan buena parte de la cavidad cefalotorácica y la parte media dorsal del abdomen. Esta selección se hizo algo complicada en *P. schmitti* ya que debía verificarse además el espermatóforo. Todo parece indicar que el mismo se desprende fácilmente puesto que en plena época de reproducción sólo aproximadamente 2 de cada 10 hembras maduras lo tenían.

Durante el estudio realizado, el 81,4% de las hembras de *P. duorarum notialis* seleccionadas desovaron y 93,7% de

estos desoves fueron viables. En *P. schmitti* el 100% de las hembras escogidas desovaron, siendo viables todos los desoves. Sin embargo, el número de hembras de *P. schmitti* que se pudo recoger en los arrastres fue siempre mucho menor.

3.3 *Traslado*

El traslado de las hembras al laboratorio se realizó preferiblemente en las primeras horas de la mañana puesto que si el traslado se efectúa por la noche es posible que algunos ejemplares desoven esa misma noche, y si éste es durante horas de la tarde puede ocurrir el desove antes de llegar las hembras al laboratorio.

En base a las experiencias de 20 viajes, resultó recomendable la utilización de recipientes de 40 litros de capacidad en los que se depositaban entre 20 y 25 hembras. Se mantuvo una temperatura de agua entre 24 y 26°C y un volumen de aireación de 1 litro por minuto^{-1}. En estas condiciones, la supervivencia media fue el 87% para *P. duorarum* y el 88% para *P. schmitti*, habiendo sido el tiempo promedio de traslado de 8 horas.

4 Desove

Las hembras fueron depositadas para el desove en recipientes cilíndricos con 12 litros de agua de mar y un estrechamiento en el fondo donde se conectaba la aireación. La temperatura siempre estuvo entre los 25 y 30°C y la salinidad entre 30 y 35 partes por mil.

4.1 *Hora de Desove*

Todas las hembras de *P. schmitti* portadoras de espermatóforo desovaron la primera noche. El 80% de éstas desovó entre las 23·00 y las 03·00 horas, y en algunos casos desde las 22·00 hasta las 05·00 horas. El 76% de las hembras de *P. duorarum* desovó la primera noche, y el 23% la segunda, habiéndose registrado 2 casos donde los animales desovaron apenas la tercera noche. El 72% de los desoves tuvo lugar entre las 22·30 y las 01·00 horas. Varios autores piensan que diferentes factores influyen en la hora de desove. Durante estas experiencias, no se han observado diferencias entre distintas épocas del año ni tampoco durante cambios de iluminación o la temperatura del ambiente.

4.2 *Mortalidad de Hembras Después del Desove*

Las observaciones realizadas con 100 hembras de cada especie dieron los siguientes resultados: *P. duorarum* 4% y de *P. schmitti* el 33% de individuos muertos. La mortalidad incrementó entre las hembras de mayor tamano, muriendo todos los ejemplares que pasaron los 75 g.

4.3 *Fecundidad*

Se determinó la fecundidad en 50 hembras de cada especie. Además, se hizo la disección a los ejemplares después del desove, determinándose que más del 80% de los huevos son expulsados generalmente, quedando casi siempre algunos en los lóbulos abdominales. En el Cuadro I se relacionan los resultados obtenidos.

5 Experiencias con huevos y estadios larvales

5.1 *Salinidad*

5.1.1 *Acondicionamiento.* Antes de determinar el rango de tolerancia del huevo y los estadios larvales a la salinidad se estudió el efecto que tiene el cambio brusco o adaptación progresiva. A tales efectos, se realizaron experimentos con los huevos y estadios nauplio, protozoea I y protozoea III de *P. schmitti.*

Los niveles de salinidad probados fueron entre 15 y 50 partes por mil con intervalos de 5 partes por mil. La salinidad inicial fue de 35 partes por mil. En los casos de acondicionamiento paulatino ésta se aumentó o disminuyó según el caso en 5 partes por mil cada 45 minutos. Las observaciones finales se realizaron en todos los casos 10 horas después de iniciarse el experimento excepto en los huevos, donde fue preciso esperar hasta la eclosión.

Para los nauplios y protozoeas se preparó una escala cualitativa que facilitó determinar el estado de los ejemplares. A los efectos de cuantificar las clasificaciones obtenidas (bien, regular, mal y muy mal) se asignaron valores convencionales a las diferentes condiciones denominándolo el 'valor de supervivencia'.

Los resultados de la Fig. 1 indican que el cambio progresivo en las salinidades extremas favorece notablemente las posibilidades de supervivencia.

5.1.2 *Supervivencia a distintas salinidades.* Se realizaron experiencias con salinidades entre 15 y 50 partes por mil a intervalos de 5 partes por mil con los huevos y estadios de nauplio y protozoea I para ambas especies así como de protozoea III y mysis III para *P. schmitti* solamente. Todos los ejemplares fueron acondicionados previamente a distintos niveles de salinidad. Para determinar la supervivencia se contaron los ejemplares que pasaron al siguiente estadio de desarrollo. Los resultados obtenidos (Fig. 2) evidencian que el rango de tolerancia al cambio de la salinidad se hace mayor a medida que los estadios larvales se suceden.

6 Influencia de la salinidad y de la temperatura sobre el tiempo de desarrollo

Para determinar la influencia de la salinidad y la temperatura del agua sobre el tiempo en desarrollo de los estadios, se realizaron experiencias con huevos y nauplios de *P. schmitti*, con salinidades entre 15 y 50 partes por mil a las temperaturas entre 25,5 y 28,5°C. En los Cuadros II y III se observan salinidades que podrían considerarse óptimas puesto que en ellas el desarrollo se llevó a cabo más rápidamente. Se notó un marcado efecto de la salinidad sobre el tiempo de desarrollo, siendo mayor aún la influencia de la temperatura. La primera eclosión de los huevos, bajo la salinidad de 25 partes por mil, tuvo lugar, a las 13 horas con una temperatura del agua de 28,5°C, mientras que en la temperatura de 25,5°C esta fue a las 17 horas. En

CUADRO I
LA FECUNDIDAD PROMEDIO Y LA RELACIÓN ENTRE LA FECUNDIDAD Y EL DESOVE

Especie	*Menor (g)*	*Mayor (g)*	*Fecundidad promedio*	*Ecuación de regresión entre la fecundidad y el peso*	*r*
Penaeus schmitti	19	61	169 000	F: $(6{\cdot}92 + 4{\cdot}2P)10^3$	0,98
P. duorarum notialis	11	45	128 000	F: $(54{\cdot}27 + 2{\cdot}55P)10^3$	0,83

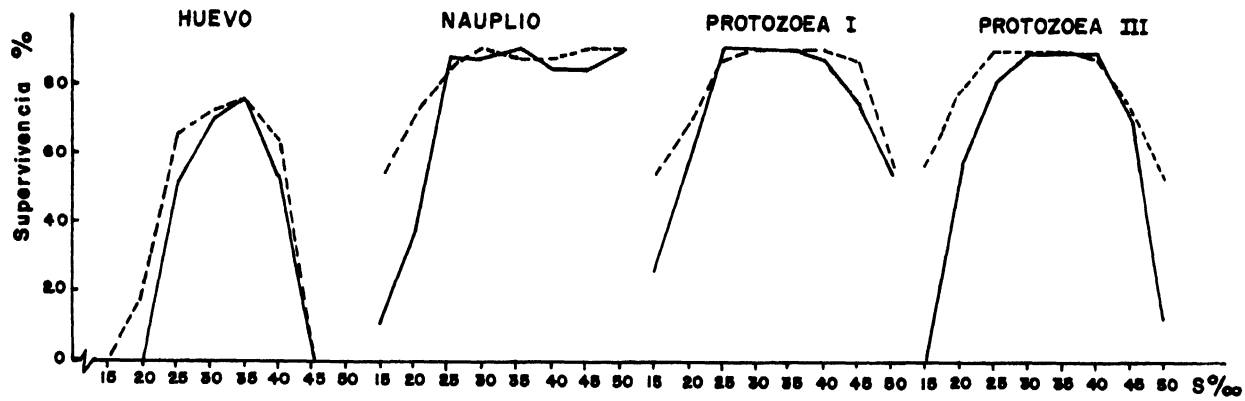


Fig 1. Valor de supervivencia de diferentes estadios larvales de *Penaeus schmitti* a cambios bruscos de salinidad (—) y con acondicionamiento paulatino (- - -)

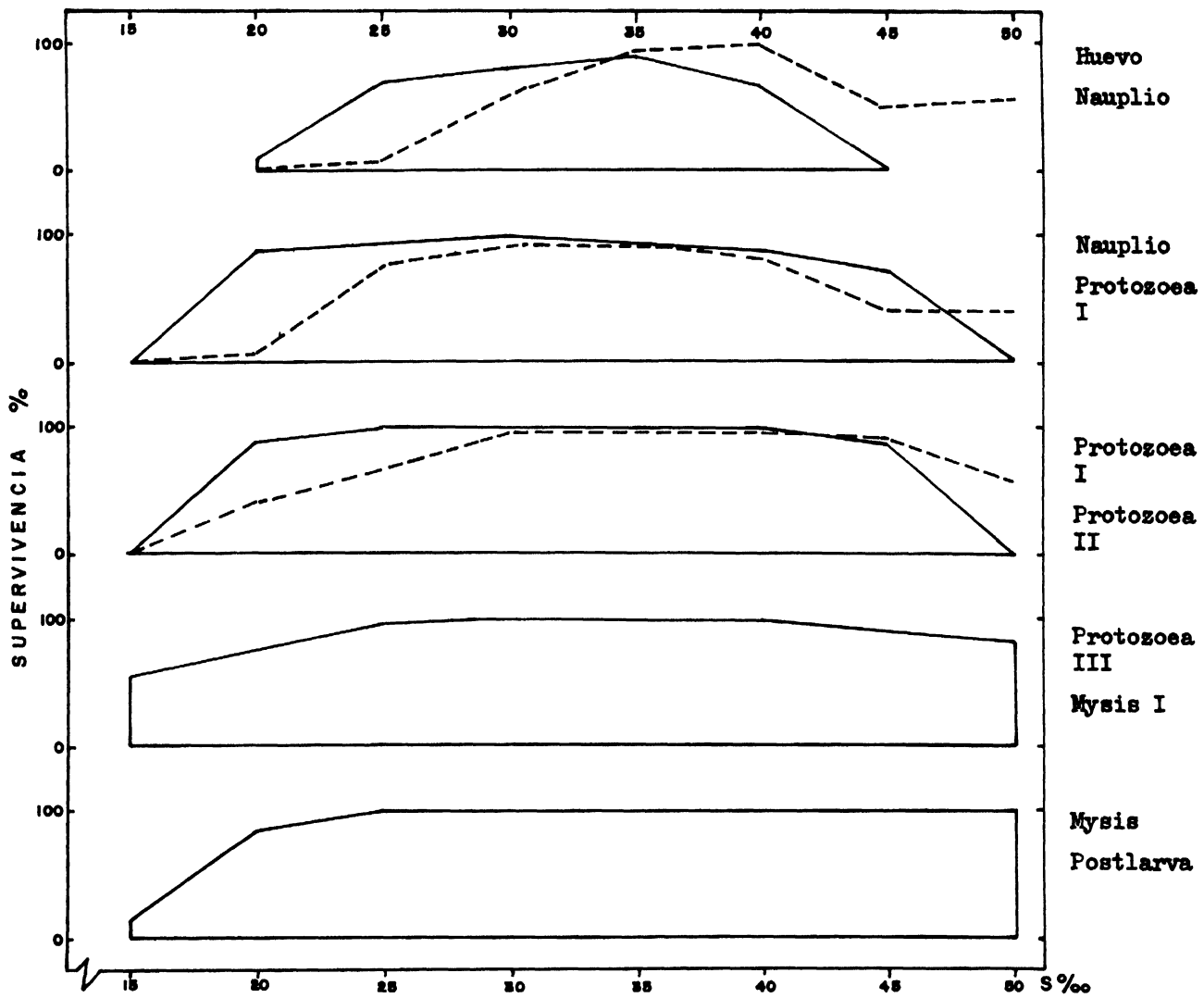


Fig 2. Supervivencia de los estadios larvales de *Penaeus schmitti* (—) y *P. duorarum* (- - -) a distintas salinidades

el caso de los estadios nauplios, el primer paso a protozoea se observó en el agua con temperatura de 28,5°C a las 46 horas mientras que en 25,5°C, el mismo tuvo lugar a las 86 horas.

7 Alimentación

Aunque no se realizaron pruebas que determinarían los valores nutricionales de diferentes algas se cree importante hacer algunas consideraciones sobre aspectos observados en el proceso de cría de los ejemplares empleados en los experimentos. Durante las experiencias con la fase protozoea utilizamos *Dunaliella tertiolecta* en una concentración de $(80 \pm 20) \times 10^6$ células por litro, con muy buenos resultados. En otras pruebas realizadas, no discutidas en este trabajo, se usaron *Platymonas* sp. y *Tetraselmis* sp. también con buenos resultados, no habiendo sido satisfactorios con *Chlamydomonas coccoides* y *Nannochloris* sp.

CUADRO II

EL DESARROLLO Y LA SUPERVIVENCIA DEL HUEVO HASTA LA ECLOSIÓN PARA AMBAS ESPECIES EN DISTINTAS TEMPERATURAS Y SALINIDADES

Temperatura (°C)	*Horas a partir del desove*	*Supervivencia* (%)							
		Salinidad (*pp mil*)							
		15	20	25	30	35	40	45	50
25,5	13	0	0	0	0	0	0	0	0
	15	0	0	0	0	0	0	0	0
	17	0	0	16	30	40	51	0	0
	19	0	3,7	49	58,3	59,1	63,3	0	0
	21	0	16,0					0	0
28,5	13	0	0	8,9	29	31	0	0	0
	15	0	2,5	24,2	52,5	60	11,7	0	0
	17	—	—	—	—	—	—	—	—
	19	0	11,6	68,2	83,3	91,6	61,4	0	0
	21	0							

CUADRO III

EL DESARROLLO Y LA SUPERVIVENCIA DE LOS ESTADIOS NAUPLIOS HASTA PASAR A ESTADIO PROTOZOEA PARA *Penaeus schmitti*

Temperatura (°C)	*Horas a partir del desove*	*Supervivencia* (%)							
		Salinidad (*pp mil*)							
		15	20	25	30	35	40	45	50
25,5	36	0	0	0	0	0	0	0	0
	46	0	0	0	0	0	0	0	0
	56	0	0	0	76	50	35	0	0
	66	0	17	9	86	83	45	0	0
	76	0	66	73	88	84	89	17	9
	86	19	81	81	93	88	90	55	19
28,5	36	0	0	0	40	8	4	0	0
	46	0	70	100	100	60	14	0	0
	56	0	96			95	80	50	0
	66	0					86	78	0
	76	0							6
	86	0							

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The Economics of Kuruma-Ebi (*Penaeus japonicus*) Shrimp Farming

Y. Hirasawa and J. Walford

Abstract

Practical aquaculture of the Kuruma-ebi shrimp (*Penaeus japonicus*) began 10 years ago in the Seto Inland Sea area of Japan, and has since spread to Amakusa and Kagoshima, two coastal areas in south-western Japan. Culture production has increased from an estimated 200 tons in 1965 to an estimated 1 300 tons in 1974, compared with the yield from capture fisheries which has ranged from 1 263–2 900 tons during the same period. This shrimp culture industry in Japan has developed because: (*i*) the price of cultured shrimp is high, and (*ii*) the high price enables culturists to adopt intensive culture techniques.

The demand for cultured Kuruma-ebi in Japan is high, and it is expected that this demand will continue to rise. Despite increased operating costs, the average selling price of cultured shrimps has not changed over the past five years because of the steadily increasing culture production. The price of cultured shrimp produced in the different regions varies considerably, however, depending on the ability to provide marketable shrimps during off-season periods.

An assessment is made of the economic viability of farms in the three producing regions. Extensive and semi-intensive farms, which are established in the Seto Inland Sea and Amakusa regions, have relatively high production per man-year, low production per unit area and generally prove to be economically viable operations. Intensive farms established in the Kagoshima region, however, are not considered profitable operations at this stage, and it is suggested that improving feed conversion would be the most effective way of making these farms economically viable. The economics of a successful farm now in operation are considered, in which the importance of using artificial feeds to replace the dwindling resources of natural foods is stressed.

Based on the experience in Japan, it is recommended that the following factors should be considered when developing shrimp farming in other areas: (*i*) availability of a reliable supply of seed at low cost; (*ii*) maintenance of good water quality in production facilities; (*iii*) availability of feeds; (*iv*) the species available in the area and their suitability for culture; and (*v*) the importance of conducting field surveys before initiating shrimp culture projects.

L'économie de l'élevage des crevettes Kuruma-ebi (*Penaeus japonicus*)
Résumé
L'élevage de la crevette Kuruma-ebi (*Penaeus japonicus*) a commencé il y a dix ans dans la région de Seto, dans la mer intérieure, et s'est depuis lors diffusé vers Amakusa et Kagoshima, deux zones littorales du sud-ouest du Japon. La production s'est accrue passant d'un montant estimé de 200 tonnes en 1965 à quelque 1 300 tonnes en 1974, alors que le rendement des pêcheries de capture se situait entre 1 263 et 2 900 tonnes pendant la même période. L'industrie crevettière japonaise s'est développée pour les raisons suivantes: (*i*) le prix de la crevette d'élevage est élevé et (*ii*) ce prix élevé permet, aux aquaculteurs de pratiquer des techniques de culture intensive.

La crevette d'élevage Kuruma-ebi fait l'objet d'une forte demande au Japon, et l'on pense que cette demande continuera à augmenter. Malgré l'accroissement des frais de fonctionnement, le prix de vente moyen des crevettes de culture n'a pas changé durant les 5 dernières années du fait des progrès réguliers de la production aquicole. Cependant, le prix de la crevette de culture produite en différentes régions varie considérablement selon les possibilités d'approvisionnement du marché en crevettes pendant la saison morte.

Le document évalue la viabilité économique des fermes aquicoles dans les trois régions de production. Les exploitations d'aquaculture extensive et semi-intensive établies dans les régions de Seto et d'Amakusa, dans la mer intérieure, ont un taux de production relativement élevé par personne et par an, un taux de production faible par unité de surface, et se révèlent généralement viables du point de vue économique. Par contre, les exploitations d'aquaculture intensive établies dans la région de Kagoshima ne semblent pas constituer des opérations rentables au stade actuel, et l'on suggère qu'une amélioration des taux de conversion alimentaire serait le moyen le plus efficace de rendre ces entreprises économiquement viables. Le document examine les facteurs économiques d'une ferme aquicole fonctionnant actuellement dans des conditions fructueuses, en soulignant qu'il importe de recourir aux aliments artificiels au lieu d'utiliser des ressources naturelles qui se raréfient.

Sur la base de l'expérience acquise au Japon, l'on recommande de tenir compte des facteurs ci-après en installant des fermes crevetticoles en d'autres régions: (*i*) un approvisionnement en frai peu coûteux et auquel on puisse se fier; (*ii*) le maintien d'une bonne qualité de l'eau dans les installations de production; (*iii*) la possibilité de se procurer des aliments pour poisson; (*iv*) l'existence d'espèces qui se prêtent à l'élevage dans la région et (*v*) l'importance des prospections sur le terrain avant la mise en œuvre des projets de crevetticulture.

Aspectos económicos del cultivo de camarón Kuruma-ebi (*Penaeus japonicus*)
Extracto
El cultivo del camarón Kuruma-ebi (*Penaeus japonicus*) comenzó en el Japón hace 10 años en el mar interior de Seto y desde entonces se ha extendido a Amakusa y Kagoshima, dos áreas costeras en el sudoeste del país. La producción mediante cultivo ha aumentado de aproximadamente 200 toneladas en 1965 a 1 300 en 1974. El rendimiento de la explotación pesquera de ese camarón durante el mismo período ha variado entre 1 263 y 2 900 toneladas. El desarrollo del cultivo del camarón en el Japón se debe a que: (*i*) el precio del camarón cultivado es elevado, y (*ii*) los altos precios permiten a los cultivadores adoptar técnicas intensivas de cultivo.

La demanda de Kuruma-ebi cultivado en el Japón es alta, y se espera que siga aumentando. A pesar del incremento de los costos de explotación, el precio de venta de los camarones cultivados no ha variado en los últimos cinco años, debido al continuo aumento de la producción. Por otro lado, el precio de los camarones cultivados producidos en las diversas regiones varía considerablemente, según las posibilidades de ofrecer camarones comercializables fuera de temporada.

Se hace una evaluación de la viabilidad económica de las explotaciones en las tres regiones productoras. Las explotaciones extensivas y semi-extensivas del mar interior de Seto y Amakusa tienen una producción relativamente alta por año/hombre, baja producción por unidad de superficie y, en general, resultan económicamente viables. Las explotaciones intensivas existentes en la región de Kagoshima, en cambio, no se consideran rentables por el momento y se sugiere que la mejor manera de convertirlas en empresas económicamente viables sería mejorar los índices de conversión de los alimentos. Se examinan los aspectos económicos de una explotación que funciona satisfactoriamente, insistiendo en la importancia que tiene el empleo de piensos artificiales para sustituir a los alimentos naturales, cada vez más escasos.

Basándose en la experiencia en el Japón, se recomienda que, al crear granjas de cultivo de camarón en otras zonas, se tengan en cuenta los siguientes factores: (*i*) asegurar un suministro confiable de semillas a bajo costo; (*ii*) mantener buena calidad del agua en las instalaciones de producción; (*iii*) disponibilidad de piensos; (*iv*) especies existentes en la zona y posibilidad de cultivo de las mismas; y (*v*) importancia de realizar ensayos sobre el terreno antes de iniciar proyectos de cultivo de camarón.

1 Introduction

In Japan, practical aquaculture of the shrimp *Penaeus japonicus* called locally 'Kuruma-ebi' started ten years ago, using abandoned salt fields in the Seto Inland Sea area. The production of shrimp by aquaculture has increased yearly, but has not yet reached the high level which many expected.

Although, generally speaking, Japanese shrimp culture uses more intensive methods than those used in other countries, many people believe that the present types of shrimp culture are still relatively extensive in comparison with other types of aquaculture in Japan. Firstly, the production of Kuruma-ebi per unit area and per man is below that of other aquacultures such as those for trout, eel and yellowtail. Secondly, shrimp culturists have used natural raw feed, especially shortnecked clams, and preferred large ponds for raising their seedlings. With raw feed, there is always a danger of spoiling water quality and pond bottom environment. It was not possible, therefore, to stock shrimp seedlings or juveniles at high densities. On the other hand, the growth rate of Kuruma-ebi is highest when shortnecked clams are used, and for this reason, the introduction of artificial feed has been slow. Shortnecked clam resources are, however, limited and are decreasing due to reclamation of their fishing grounds. At the same time, there has been increased demand for shortnecked clams for human consumption. As a result, their price has risen significantly and this trend has recently become more rapid.

There are many aquaculture industries in Japan in which the use of artificial feed has a fairly long history, but an artificial feed for shrimps was not developed until three years ago at Kagoshima Fisheries Laboratory. Thanks to this work, Japanese shrimp culture has the possibility of achieving stability of management and is now at the threshold of its second expansion.

The aims of this paper are to: summarize the experience gained in Kuruma-ebi culture in Japan from the economic and technical points of view; evaluate each type of culture management; and forecast the direction of this industry. The techniques and varied styles of management of this industry have become increasingly complex, delicate and sophisticated, and have had a great influence on other aquacultures. A review of experience gained in Japanese Kuruma-ebi culture may be useful for other countries not only because it includes many different types of management but because of its fairly long history of practical operation.

2 Economic basis of Kuruma-ebi culture in Japan

2.1 *Kuruma-ebi production by fishing and by culture*

The production of Kuruma-ebi both by fishing and through culture is concentrated in the coastal waters of southwestern Japan (Fig. 1). Kuruma-ebi live in the sandy bottom of the sea and cannot survive at temperatures under 4° or 5°C. In the central and northern parts of Japan the water temperature is rather cold and sandy bottom areas are rather limited; there is little production of Kuruma-ebi in these areas.

Fig. 2 depicts the amount of Kuruma-ebi production by both fishing and culture from 1965 to 1974. In 1965, the yield of Kuruma-ebi by fishing was about 2 900 tons. It went down gradually to only 1 263 tons in 1970, and then recovered rapidly to attain its approximate 1965 position by 1974. It is difficult to provide an explanation for this

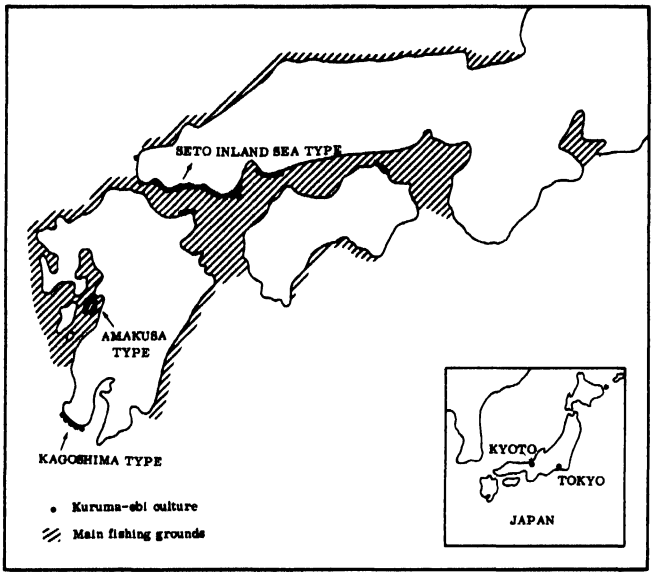


Fig 1. Map of Kuruma-ebi production areas in Japan

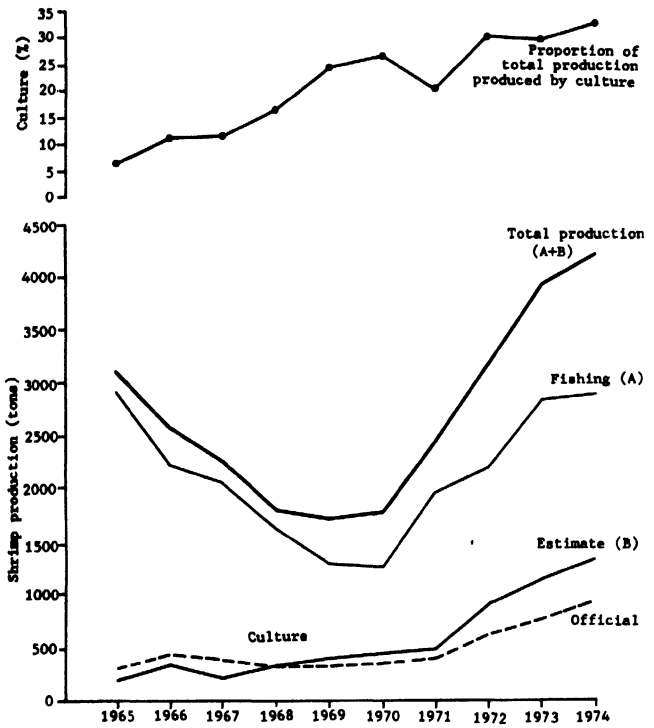


Fig 2. Yearly production of Kuruma-ebi

recovery, but it is almost certain that the coastal water is cleaner than that of the sixties and it may be partly due to shallow water restocking with post-larval Kuruma-ebi.

The production of cultured Kuruma-ebi has been increasing gradually from 305 tons in 1965 to 740 tons in 1974 according to the official statistics of the Ministry of Agriculture and Forestry. These statistics usually underestimate production, however, especially in aquaculture. We have, therefore, amended the official statistics using the total pond area under cultivation annually and the annual production of Kuruma-ebi per m^2. We are sure that the statistics based on pond area are more accurate than the official reports of production. The information concerning annual production per m^2 was collected during our field research and, based on this, we can make estimates of the total production of cultured Kuruma-ebi at each of the three major production centres. According to our calculations, production of cultivated Kuruma-ebi was about 200 tons in 1965 and 1 300 tons in 1974. The reason that the 1965 production is higher in the official statistics than in our calculations is due to their inclusion of shrimps which had been caught by fishing and stocked in ponds. The production of cultured Kuruma-ebi in 1974 in the three main centres was as follows: 500 tons in Seto Inland Sea, 720 tons in Amakusa, and 80 tons in the Kagoshima area.

2.2 *Demand for Kuruma-ebi and its price*

In Japan, Kuruma-ebi is a delicacy that commands the highest price among fishery products owing to its delicious taste, especially when cultured and shipped alive. (Cultured Kuruma-ebi is always shipped alive to the large cities.)

The price of Kuruma-ebi is quite different depending on whether it is alive or not (Fig. 3). A considerable proportion of the production from fishing consists of dead shrimps because they often die during fishing operations and transport. Although the prices fluctuate each year, the price of live cultured shrimp is usually double that of dead shrimp. The price of dead Kuruma-ebi has been rather stagnant

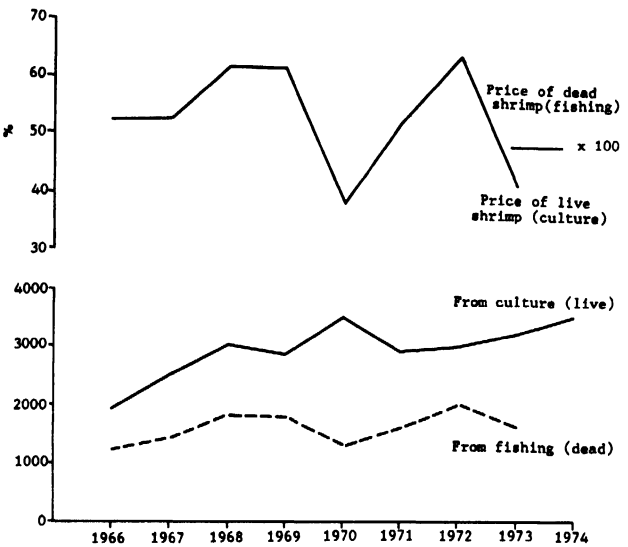


Fig 3. Changes in the price of Kurima-ebi from 1966 to 1974

lately because of serious competition from imported frozen shrimps and because the harvest from fishing has increased.

Most Japanese shrimp culturists and biologists are concerned because the price of cultured Kuruma-ebi has remained at the same level despite increased production costs. On the other hand, it is remarkable that the price has remained stable for five years notwithstanding the threefold increase in the production of cultured Kuruma-ebi from 300 tons in 1968 to 900 tons in 1972. What is more, since 1974 the price has started to go up again and this during a period of severe economic recession.

In general, the demand for high-class aquaproducts in Japan is very high, the same as for meat, and it is expected that the demand for cultured products, especially Kuruma-ebi, will continue to rise. The following functional formulae for cultured products were derived by Hirasawa using data from 1950 to 1970:

	R	Period	
$\log Q = 5{\cdot}189 + 1{\cdot}339 \log Y - 1{\cdot}426 \log P$	0·980	1955–72	(1)
$\log Q = 3{\cdot}142 + 1{\cdot}119 \log Y - 0{\cdot}682 \log P$	0·947	1955–63	(2)
$\log Q = 5{\cdot}469 + 1{\cdot}493 \log Y - 1{\cdot}611 \log P$	0·990	1963–72	(3)

Where Q = the amount of consumption *per caput* per annum
Y = income *per caput* per annum
P = price of cultured products
R = coefficient of correlation

Income elasticity of demand and price elasticity in the case of cultured products are extremely high compared to other foods; this shows the strength of demand for cultured products. Although a high rate of growth cannot be expected in the Japanese economy over the next ten years (owing to the oil 'crisis'), some degree of growth can be anticipated, and income *per caput* may continue to increase steadily at the rate of 3–4% yearly.

In the above formulae, income elasticity and price elasticity during the period of 1963–72 are both somewhat higher than during the period of 1955–63. This shows that the demand for cultured products has been increasing in recent years.

Hirasawa has also calculated the elasticity of demand for cultured Kuruma-ebi from 1965 to 1974. According to this calculation, the demand for cultured Kuruma-ebi is surprisingly high in comparison to the demand for other cultured products; the income elasticity of Kuruma-ebi was found to be 2·18. From this figure it can be ascertained that if *per capita* income in Japan rises by 10% the demand for Kuruma-ebi will increase at the rate of 22%. In developed countries it is very rare for foods to have an income elasticity of over 0·5. From the point of view of demand, then, the forecast is hopeful, but there are several problems in this industry. One of these problems is the continuing tendency for a gap to open between the producer's selling price and his cost of production.

Management of the Kuruma-ebi culture industry did not reach a position of balance during the sixties because of lack of experience. Upon entering the seventies, techniques and administration have greatly improved, and a new production centre is emerging in Amakusa. This has meant that since 1970, the total production has increased rapidly resulting in stagnation of the price of Kuruma-ebi. On the other hand, production costs, particularly feed costs, have gone up at a surprising rate and the economic condition of Kuruma-ebi farms has recently declined.

Fortunately, at this critical time a new cultural technique using an artificial feed has been introduced, bringing new prospects for development of Kuruma-ebi culture. This artificial feed was developed as an integral part of a double-bottom circular tank culture system called the 'Kagoshima method'.

3 Management of Kuruma-ebi farms

3.1 *Location of farms and type of culture*

There were 83 Kuruma-ebi farms in Japan in 1974. Each of the three major production centres (Fig. 1) has its own characteristics with respect to: period of shipment of harvest and culture methods and techniques.

Fishing for Kuruma-ebi begins in April and may end in November; the busiest season is from June to September. The amount of shrimp caught by fishing is larger than that which is cultured, and the producers of cultured Kuruma-ebi do not ship their products during this period when wild Kurami-ebi are caught and shipped at a relatively low price. Moreover, this is not a good time for shipping cultured Kuruma-ebi as they have not yet reached suitable market size.

The spawning and hatching of Kuruma-ebi usually begins at the end of March or the beginning of April. Seedlings are about 10–15 mm long and weigh about 0·01–0·02 g. Nursery ponds are stocked with seedlings during April or May and the juveniles transferred to rearing ponds during June or July. The commercial size for Kuruma-ebi is usually over 18 g and most of the cultured shrimps will reach this size by October. Fig. 4 shows that shipment of cultured shrimp from the Seto Inland Sea area starts at the end of August. The reason for shipment at this time is not primarily to make sales but to thin out the populations in the ponds. (Heavy mortalities usually do not occur after September, hence the advisability of thinning out at this time.) Most of the shrimp cultured in the Seto Inland Sea area are shipped to market during November–January and are all gone by the end of February. *Penaeus japonicus* will hibernate in the sand when the water temperature falls to about 12°C. In the Seto Inland Sea area, the water temperature of the ponds sometimes falls below 0°C during the winter, and cultured Kuruma-ebi cannot live over the winter. In order to get these shrimp to market alive, they must be taken out of the ponds before the end of the year or shortly thereafter.

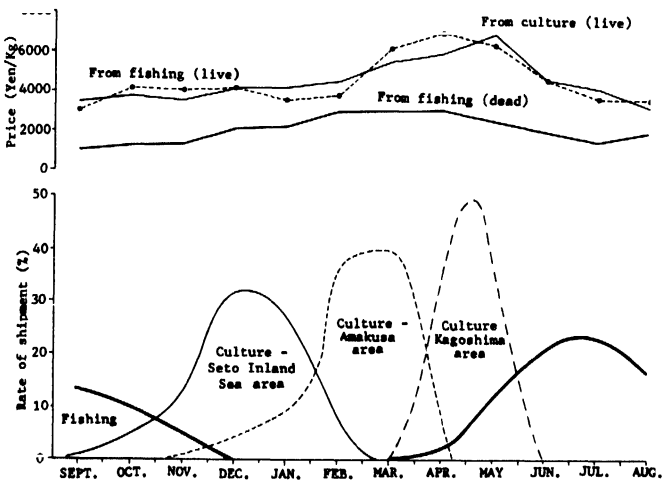


Fig 4. The price of Kuruma ebi (in 1974) and composition of shipment by area and by month

In the Amakusa area, in a more southern part of Japan, the water temperature is warmer, rarely falling below 10°C. Cultured Kuruma-ebi can overwinter here, hibernating in the sandy bottom without feeding. During this hibernation which ends with the advent of spring, Kuruma-ebi become very weak. Their price is very high in April and May because the amount shipped to market (including wild shrimp) is very small. The Amakusa culturists would, of course, be glad to ship their shrimps during these profitable spring months, but if they did, a considerable part of the shipment would arrive dead because of their weakened condition. As a result, shipment from the Amakusa area has to be completed in March.

In the Kagoshima area, in the most southern part of Japan and somewhat warmer than Amakusa, Kuruma-ebi can be easily kept over winter. Therefore, they can be shipped in April and May and the highest prices obtained. As is shown in Fig. 4, the price is fairly low when the production of Kuruma-ebi from the capture fishery is being shipped. Then, as soon as the shipment of fishing

production slackens in September, the shipment of cultured Kuruma-ebi begins: first, from the Seto Inland Sea area; then from the Amakusa area; finally from the Kagoshima area, mainly by air. The Kagoshima area has the advantage of being able to get a higher price for shrimp than the other areas, but this is not always enough to ensure profitable operation.

Depending on their location, Kuruma-ebi farms use different methods of culture and management. Table I shows the characteristics of several types of Kuruma-ebi farms.

In the Seto Inland Sea area, the cradle of this industry in Japan, the culture method is based on the use of abandoned salt fields. The ponds here are usually large, situated on land and connected with the sea by sluices. In order to supplement dissolved oxygen and encourage the growth of desirable diatoms and dinoflagellates in the ponds, the culturists in this area have to work hard to maintain suitable conditions by regulating the flow of water through sluice gates. Most of the Seto Inland Sea area farms are characterized by a rather 'extensive' type of culture, which we shall term Type A. The shrimp production per m^2 is rather low compared with that of the other types (see Table I). The Seto Inland Sea area also has another type of culture which we have termed Type B. Its ponds are smaller than those of Type A, are equipped with many gates to permit good water exchange, and have other facilities such as aeration apparatus and motor-driven propellers to provide supplementary dissolved oxygen. This makes it possible to rear a larger number of shrimps per unit area. Type B can be regarded as a 'semi-intensive' type together with the Amakusa area farms, termed Type C (see Table I).

The merit of the Seto Inland Sea farms is that they can benefit to some extent from natural food. Four or five individual shrimp per m^2 can be kept in the ponds of the A and B types without any feeding, because there are plenty of naturally produced organisms in the brown water found in these ponds. As a result, the conversion ratio from feed to shrimp is the highest among the various types of shrimp culture, and the cost of production is rather low.

In the Amakusa area the ponds (Type C) are formed by low stone or concrete dikes with a high netting on top extended out from the shore to enclose an area of shallow sea. The use of netting means that the dikes themselves can be so low that they are below water level except at low tide and the exchange of water is, therefore, much better than in Type A and B ponds. From a technical point of view, it should be possible to rear considerably more shrimp with this system, but at present its production (Type C) is much lower than Type B. We believe that this is largely due to lack of experience on the part of the Amakusa culturists who changed only four years ago from their original business of just holding—rather than rearing—Kuruma-ebi. It is expected that their techniques will improve in the near future and production increase. Therefore, we regard Type C as a 'semi-intensive' type even though its present level of production is low. The disadvantage of Type C compared with A or B is that a greater amount of feed is needed. The good water exchange prevents a build-up of phytoplankton and other organisms and natural food in the ponds is much less than in the Seto Inland Sea types.

Lastly, there are Types D and E in the Kagoshima area. The characteristic feature of these is their use of small circular water tanks with a higher rate of water exchange than in the other systems (A–C). Type D is rather old; the tanks used do not have double bottoms. Water exchange is about twice daily. Type E is the newest and most advanced system in all of Japanese aquaculture from a technical and management point of view. As its tanks have double bottoms, the water can pass continuously through a layer of sand which forms the first bottom. In this way, it is possible to supply enough water and oxygen for the shrimps and to get rid of the remains of feed and faeces through a central outlet. The maximum rate of water exchange is about four times daily; a higher rate will cause the sandy bottom to harden and the shrimp will not be able to burrow into it.

The merit of the Kagoshima intensive culture method is the high production both per unit area and per worker. The originators of this intensive system believed, at the beginning of their experiments, that the extensive methods of the Seto Inland Sea type would have to be abandoned in the future due to the high cost of land and feed, shortage of manpower, low productivity, and water pollution. The disadvantage of this intensive method is the impossibility of utilizing latent natural productivity owing to the high rate of water exchange. Moreover, because of the very high density of Kuruma-ebi on the small bottom area, the growth of shrimps is hindered by overcrowding. Under these conditions, maintenance of the growth rate depends entirely on the use of more effective artificial feed. If raw feed were used, as in the other areas, the water quality and bottom environment would soon deteriorate.

Generally speaking, the growth rate of cultured shrimp or other crustaceans or finfish is highest when the amino-acid composition of their feed is the same as that of their own protein. Scientists of Kagoshima Fisheries Laboratory used this relationship as the basis of their experiments to develop a special artificial feed. The amino-acid

TABLE I
CHARACTERISTICS OF EACH TYPE OF KURUMA-EBI CULTURE FARM

	Type of pond	*Area per pond (ha)*	*Water exchange rate/day*	*Production (per m^2) (g)*	*Feed conversion ratio (wet wt. equiv.)*	*Type of culture*
Seto Inland Sea						
Type A	Converted from	1–5	0·25	250–300	10–14:1	Extensive
Type B	salt fields	0·5–1	0·5	500–600	10–14:1	
Amakusa	Enclosure with dike					
Type C	and netting	0·5–1	0·9	250–350	12–15:1	Semi-intensive
Kagoshima						
Type D	Circular water	0·1	2·0	1 800–2 000	22–22:1[a]	Intensive
Type E	tanks on land	0·1	4·0	2 700–3 000	17–20:1[a]	

[a] Types D and E use dry feed exclusively; for purposes of this table, the actual conversion ratio for dry feed was multiplied by a factor of 6 to give the raw feed equivalent

composition of Kuruma-ebi protein is most similar to that of molluscs such as shortnecked clams and, to a lesser degree, to that of squid and some small shrimps. In the first artificial feed, squid meal was an important ingredient but at that time squid was relatively cheap.

Unfortunately, squid has become very expensive due to short supply and an increase in its processing for human consumption. When private companies first started culture based on its use, the price of artificial feed for Kuruma-ebi was in the range of Yen 500–600/kg. In 1974 the price of this artificial feed was over Yen 1 000/kg. With such a high feed cost, no Kuruma-ebi culture farm could have continued to exist for long. Early in 1975, the composition of the artificial feed had to be changed with cheaper ingredients substituted for squid. There was no alternative even if this meant that the efficiency of the feed was diminished. The best conversion ratio achieved with the first formula was about 2–2·5:1; with the new one, it is down to the level of 3–3·5:1. It is conjectured that the new feed contains a little soybean meal, but the details concerning its contents have not yet been revealed.

With some sacrifice in efficiency of conversion, the new feed has become quite cheap, Yen 700/kg. This means that the price of the new artificial feed is approximately the same as for an equivalent weight of raw feed consisting of small shrimps, mussels and imported frozen oysters or shortnecked clams from Korea. These raw materials are relatively cheap, but handling raw feeds involves extra costs, *eg*, transport, refrigeration, and manpower. If these extra costs are added to the original cost of the raw materials, the price of raw feed is about the same as that of artificial feed. Generally speaking, the equivalent conversion ratio of raw feed is six times that of artificial feed. As shown in Table I, the production of shrimp per m^2 is very high with the intensive method. On the other hand, its feed conversion ratio is poor compared with that of the more extensive methods, because the intensive method relies completely on a man-made environment, and cannot make use of the basic productivity of more natural waters.

3.2 *The profitability of five types of Kuruma-ebi farms*

It is usually very difficult to get economic data from private aquaculture farms. The figures in Table II are derived from the authors' field research, and reflect averaged data for each type of farm. The economic situation of individual private farms changes from year to year according to fluctuations in production. The culturists can achieve their planned annual production if their shrimps do not die in large numbers, but they often fail to get the crop they expected due to some mishap during the rearing period. Therefore, we have had to make some adjustments to the data received from private companies in these cases of abnormal production.

As described above, the selling price of Kuruma-ebi becomes higher in the order of Type A, B, C . . . , due to differences in timing of their shipments. Production costs per kg for each type are also very different. Types A and B in the Seto Inland Sea area have the lowest costs, and therefore produce some profit. Type C in the Amakusa area also makes some profit, because although its costs are higher than those in the Seto Inland Sea area, the selling price of the shrimps is also higher. Types D and E in the Kagoshima area cannot make any profit at present because, although their selling price is very high, their costs are even higher.

Each item of cost is examined in Table II. Firstly, shipment cost, which includes transport, packing materials, sales commission, *etc*, is cheap in the Seto Inland Sea area (Types A and B) because of relatively short distances to market. Secondly, feed costs which depend largely upon the effectiveness of the feed used, are very different for each area. The conversion ratio of feed is good in the Seto Inland Sea area, therefore the cost of feed is cheaper. Thirdly, the depreciation costs of Types A and B are lower than the others due to their small investment in fixed assets, *eg*, pond construction and water pumps. Depreciation costs of land have been omitted from these calculations because it is very difficult to evaluate land costs and to decide what rate of depreciation (or appreciation) to apply. At present most of the disused salt fields have already been taken over by other industries or converted to other uses. Owing to the high cost of land, we cannot expect any expansion of the extensive type of farm.

Type D and E farms in the Kagoshima area have a history of only three or four years, during which period both types of farms have suffered considerable losses. As a result, these farms have had to borrow money from the bank, and this is the reason their interest cost is so high. If the interest for long-term capital investment only were to be included, the interest cost would be reduced by 33%. In addition to the above-mentioned costs, electricity and other costs are rather high in the intensive method, especially for Type E.

Table III gives the entire picture of the economic situa-

TABLE II
PRODUCTION COST (PER KG) OF KURUMA-EBI BY TYPE OF CULTURE IN 1974 (YEN)

	Seto Inland Sea		*Amakusa*	Kagoshima	
	Type A	*Type B*	Type C	*Type D*	*Type E*
Selling price (A)	4 100	4 700	5 200	6 000	6 000
Production cost (B)	2 900	3 500	4 600	6 900	6 400
B/A (%)	71·0	74·4	88·5	115·0	106·7
Items of cost					
Shipment	460	360	630	690	580
Seedlings	80	70	90	—	—
Feed	1 000	1 030	1 400	2 440	2 200
Wages	510	1 070	1 030	830	580
Power and fuel	100	110	120	70	400
Depreciation (excluding land cost)	110	60	230	490	390
Other	230	360	530	750	550
General management cost	200	300	100	520	260
Interest	210	140	470	1 110	1 440

tion for each type of private farm. Type A has the merit of high production per man, but the disadvantage of low production per unit area. It is a suitable system of management to use in an area where land is plentiful and cheap. On the other hand, in the case of Type B, even though this farm is also in the Seto Inland Sea area, the culturist could not get as large an area as that used in Type A. Therefore, the culture method is of the 'semi-intensive' type: Type B has a lower production per man than Type A, but a higher production per unit area. This B-type is very suitable in areas where land is rather scarce and its cost rather high, but manpower is easily available.

With respect to the actual situation in Japan, especially in the Seto Inland Sea area, there can be little expansion of the extensive type farms such as Type A in the future due to the lack of unused salt fields. Although Type B is not as good from the point of view of production per man, this type has a higher production per unit area. In Japan, at present, obtaining manpower is easy in comparison with procurement of suitable large land areas.

With Type C, production is rather low both per unit area and per man. This may be due to the lack of real shrimp culture experience in the Amakusa area and the easy-going ways of the culturists. The Amakusa area has a history of about seventy years of stocking its ponds with Kuruma-ebi caught by fishing in expectation of getting a high price. Culturists in the Amakusa area are said to be accustomed to only simple techniques of stocking their ponds, and have not been very keen to improve them. But, during our field research, we received the information that some culturists have already reached a high level of production per m^2 (about 450–500 g/m^2). It is possible to predict that in a few years the Amakusa culturists will be able to reach as high a level of production as Type B, due to the favourable natural rearing conditions of the area. Moreover, much unused coastline suitable for shrimp culture is still available.

In the case of Type D Kagoshima culture, using circulating water tanks, the production per man is of course high, but not as high as in either A or B in the Seto Inland Sea area. The reasons are twofold: (*i*) the Type D water tanks do not have a double-bottom system, and (*ii*) water exchange, which relies to a great extent on tidal ebb and flow, occurs only about twice a day. Under these circumstances, the remains of feed and faeces accumulate rapidly on the bottom and the environmental conditions for shrimp deteriorate soon after the start of culture. Laborious sweeping is necessary to clean the bottom and prevent mass mortality of the shrimp, and this requires employment of a relatively large number of people. So, in spite of its aim at being an intensive method of culture, D-type has not been able to achieve its purpose.

4 Economic viability of Kuruma-ebi culture

4.1 *Assessment of different culture techniques*

It is usually not possible to obtain detailed economic data from aquaculturists. A convenient way, therefore, to judge the economic state of any aquaculture farm is to use Hasegawa's formula to learn about the economic state of the farm concerned. If we can calculate the following relationship for any farm, it is easy to judge whether the prerequisite conditions for successful management of culture exist and whether the farm can make a profit.

$$\frac{A}{B} \geqq \frac{a}{b}$$

where A = Selling price of commercial-size product per kg
B = Price per kg of feed
a = Conversion ratio from feed to product
b = Ratio of feed cost to total cost.

Data from Tables I and II have been used below to examine the economic viability of the approximate

TABLE III
COMPARISON OF THE EFFICIENCY OF DIFFERENT TYPES OF KURUMA-EBI FARMS IN 1974

	Seto Inland Sea		*Amakusa*	*Kagoshima*	
	Type A	*Type B*	*Type C*	*Type D*	*Type E*
Total pond area ('000 m^2)	150	28	54	5·6	13·0
Production (kg/m^2)	300	580	300	1 800	2 700
Total production (tons)	45·0	16·2	16·2	10·1	35·1
Number of employees	14	7	11	5	8
Production per man (kg)	3 214	2 314	1 472	2 020	4 387
Average price per kg (Yen)	4 100	4 000	5 180	6 000	6 000
Total sales ('000 Yen)	185 000	76 000	83 000	60 600	211 000
Total cost ('000 Yen)	130 000	57 000	74 000	69 700	224 000
(Items) (%)	100·0	100·0	100·0	100·0	100·0
Shipment cost (%)	15·0	10·0	14·0	11·0	9·0
Seedlings (%)	3·0	2·0	2·0	—	—
Feed (%)	35·0	29·0	30·0	35·0	34·0
Wages (%)	18·0	31·0	23·0	12·0	9·0
Power and fuel cost (%)	3·0	3·0	3·0	1·0	7·0
Depreciation (%)	4·0	2·0	5·0	7·0	6·0
Other	8·0	10·0	11·0	11·0	9·0
General management cost (%)	7·0	9·0	2·0	8·0	4·0
Interest (%)	7·0	4·0	10·0	16·0	22·0
Profit (before tax) ('000 Yen)	55 000	19 000	9 000	9 100	13 000
Value of production per m^2 ('000 Yen)	1 200	2 700	1 500	11 000	16 000
Value of production per man ('000 Yen)	13 200	11 000	7 500	12 000	26 000
Value added per m^2 ('000 Yen)	630	150	600	4 600	6 000
Value added per man ('000 Yen)	6 800	6 012	3 000	4 300	9 500
Profit per man ('000 Yen)	3 928	2 714	818	—	—
Profit per m^2 ('000 Yen)	367	678	167	—	—

status of the different types of culture operation as they were in 1974:

Factor	*Value (Yen/kg of Production)* *Types of Farms*					
	A	*B*	*C*	*D*	*E*	*C2*[a]
A–Selling price (Table II)	4100	4700	5200	6000	6000	5200
Cost of feed (Table II)	1000	1030	1400	2440	2200	1215
Other costs	1900	2470	3200	4460	4200	3200
Total costs of Production (Table II)	2900	3500	4600	6900	6400	4415
a–Conversion ratio (Table I)	12.5	12.0	13.5	3.5	3.1	13.5
b–Cost of feed/Production cost	0.34	0.29	0.30	0.35	0.34	0.28
B–Average price per kg of feed	80	86	104	697	710	90

Type	*A/B*	*a/b*	$\frac{a/b}{A/B} \times 100$
A Raw feed	$\frac{4100}{80} = 51.3$	$\frac{12.5}{0.34} = 36.8$	71.7%
B Raw feed	$\frac{4700}{86} = 54.7$	$\frac{12.0}{0.29} = 41.4$	75.7%
C Raw feed	$\frac{5200}{104} = 50$	$\frac{13.5}{0.30} = 45$	90.0%
D Artificial feed[b]	$\frac{6000}{700} = 8.57$	$\frac{3.5}{0.35} = 10$	116.7%
E Artificial feed	$\frac{6000}{700} = 8.57$	$\frac{3.1}{0.34} = 9.12$	106.4%
C2 Raw feed at Yen 90/kg	$\frac{5200}{90} = 57.8$	$\frac{13.5}{0.28} = 48.2$	83.4%

[a] *C2*—Price of raw feed taken as Yen 90/kg instead of Yen 104/kg
[b] In 1974 Type *D* used both raw and artificial feed. However, in order to simplify the example, an adjustment has been made; it is shown as having used only artificial feed. Moreover, it is much better for this type to use artificial feed in order to maintain good water quality.

For convenience, the coefficient $(a/b)/(A/B) \times 100$ is called the 'coefficient of culture security'. If this coefficient is over 100%, the operation concerned will make a loss. If the coefficient is just 100%, the operation is just at the break-even point and will neither profit much nor lose much. The lower the coefficient is below 100%, the greater the possibility for a large profit. For Type C, the coefficient of culture security in this calculation seems relatively poor. But in 1974 Amakusa area culturists were using short-necked clams as 20% of the total feed; their feed costs were, therefore, higher than those in the Seto Inland Sea area where these clams were no longer used. The data based on the price of the feed used by Type C is not, therefore, really comparable to the data for the others. If the data for Type C are recalculated, using a feed price of Yen 90/kg, we get the result shown in column C2. In C2, the value of A/B is 57·8 instead of 50, but in this case, the weight of feed in total expenditure, that is the value of b, goes down to 0·28. Therefore, a/b becomes 48·2, and the coefficient of culture security improves to 83·4%.

When self-produced feed is used, it is necessary to make a separate calculation of the Hagesawa formula to convert self-produced feed to purchased feed, as in the case of Kagoshima Types D and E, which are the most intensive aquaculture farms, and have used artificial feed ever since they started. In order to compare them with the other types of farm, an attempt has been made to calculate the equivalent conversion ratios if raw feed were used. The conversion ratio using the new artificial feed, which does not contain as much high-priced squid meal, was found to be about 3·1:1 at Type E farm and 3·5:1 at Type D under the best conditions in 1975. A conversion ratio of 3·1:1 with artificial feed is equivalent to 18·5:1 with raw feed and 3·5:1 is equivalent to 21:1 since the conversion ratio of raw feed is taken to be six times that of artificial feed.

The data for the Kagoshima area Types D and E are not strictly comparable to the data for the other areas. The reason for this is not only that the price and conversion ratio of artificial feed are different from those of raw feed but also that the price of feed in the Seto Inland Sea and Amakusa areas includes only the cost of the feed itself; it does not include the costs of transportation, refrigeration and labour for handling and preparation which also have to be included so that data for farms using raw feed is comparable to data for farms using artificial feed. However, if allowances are made for these factors in the previous example, very similar results are obtained on the economic viability of the culture types.

The economic condition of intensive types D and E in the Kagoshima area is not stable in spite of their high selling prices. In order for these types to achieve economic viability, the culturists will have to make greater efforts to cut down their costs and to improve feed efficiency. In other words, something must be done to increase the value of A and b, or to lower the value of B and a in the Hasegawa formula.

Usually the selling price (A) is decided at the markets of large cities, and it can be assumed that the selling price is a given value outside the control of the culturist. The other way to increase the value of A/B is to reduce the price of artificial feed. On the other hand, to reduce the value of a/b, something must be done to improve the conversion ratio of feed, which reduces the value of a, and to increase the percentage of b. It is usually not very easy to improve the conversion ratio, which depends to a considerable degree on technology. But in the field of intensive culture, practical work on formulating artificial feed is just at the beginning and there is good reason to believe that the efficiency of feed can be improved. Increasing the value of b is equal to reducing all costs other than cost of feed. Of course, a reduction in the price of feed is also helpful to management. But, in this case, it is the value of A/B that is increased while the value of b is reduced. It is rather difficult to reduce costs other than expenditure for feed, for these costs are mostly dependent on previous investment and include a large proportion of fixed costs.

According to our calculations, if the conversion ratio can be improved to better than 3·0:1 and if the price of artificial feed can be reduced to Yen 650/kg and a corresponding cut in costs other than feed cost can be achieved, there is some possibility that D and E type farms in the Kagoshima area can continue production. But under the present circumstances, with its excessively high feed costs, intensive Kuruma-ebi culture has little chance of replacing the extensive and semi-intensive type farms. Furthermore, the economic base of the intensive types is rather narrow because the high price of their products would almost certainly go down if the number of this type of production unit increased and production increased. The high price of

Kuruma-ebi during the short period of April and May results from a shortage of supply at that time from both fishing and other types of culture. Therefore, an expansion of the intensive type of farm is inevitably limited. The high price of Kuruma-ebi does not last very long, and if the amount shipped during this period increases by just a little, the price may be rapidly reduced.

4.2 *Assessment of a successful farming operation*

Consideration is now given to an actual case of a Type B farm in the Seto Inland Sea area. Table IV shows the actual data for a Kuruma-ebi farm, built by nine fishing co-operatives in Yamaguchi Prefecture. This typical Type B farm has a rather small total pond area (2·8 ha) but its production is comparatively high. The number of seedlings used for stocking the ponds has not changed much over nine years, but the amount of production has increased surprisingly from 5·8 tons in 1966 to 16·1 tons in 1974 with large fluctuations. It is significant that the average weight per shrimp cultured has increased from year to year and production per unit area has risen to a remarkably high level.

Fig. 5 shows the profitability of this farm. The selling price per kg of product is higher than that of Type A due to good rearing. The reasons for increase in the production of this farm are mainly connected with the improvement of water management and feed supply. In the Seto Inland Sea area, it is not a good policy to let tidal waters enter freely into the ponds lest harmful algal growth occurs. Four water-gates have been built into these ponds, and, if necessary, up to 90% of the water can be changed per day except during neap tides. Therefore, in the critical period during August and September, the water exchange can be easily increased to provide more oxygen in the case of emergency. As the pond area is rather small, water quality can be controlled with the greatest possible care. Many more people are employed, as compared with Type A, to look after the ponds. If there is an emergency, *eg*, oxygen deficiency, red water or rapid growth of harmful algae, it is possible with more manpower to reduce the effects of the crisis. On A-type farms, however, water quality cannot be controlled during an emergency because of the size of the ponds. Therefore, stocking densities on extensive type farms are not high, to ensure a high survival rate of the shrimp.

In spite of the small pond area, the amount of production at the Ube Kuruma-ebi farm has increased more than

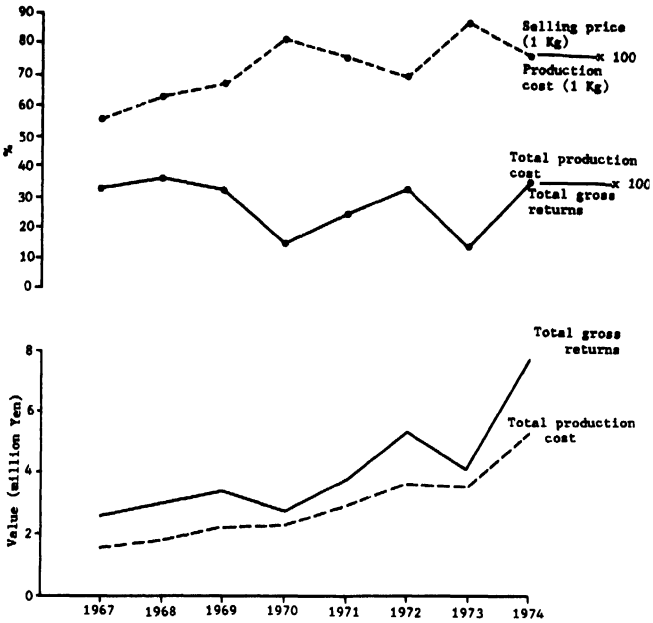


Fig 5. Cost of production and earnings of Ube Kuruma-ebi Farm

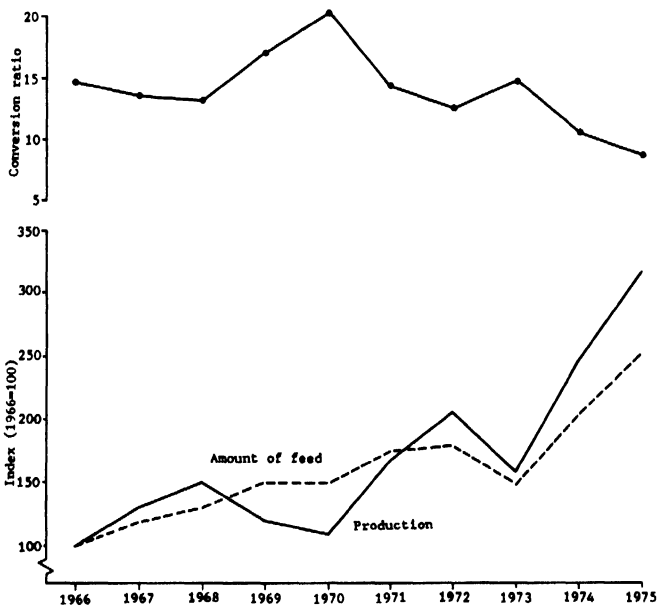


Fig 6. Relation between production and feed at Ube Kuruma-ebi Farm

TABLE IV
DETAILS OF PRODUCTION AT THE UBE KURUMA-EBI FARM (TYPE B)

Year	*No. of seedlings ('000) (A)*	*Production*		*Yield rate (B/A) (%)*	*Average wt/piece (g)*	*Productivity/ m^2 (g)*	*Total landing value (Yen '000)*	*Price/ kg (Yen)*
		No. of pieces ('000) (B)	*Quantity (tons)*					
1966	870	532	5·8	61	11·0	212	11 391	1 952
1967	800	542	7·5	68	13·9	272	26 242	3 490
1968	800	572	8·5	71	17·5	308	29 128	3 423
1969[a]	800	297	7·0	37	22·1	255	32 957	4 686
1970[b]	800	355	6·3	44	18·2	227	26 919	4 294
1971	800	636	10·1	79	20·9	367	37 321	3 690
1972	680	469	12·4	69	25·9	451	52 635	4 234
1973[c]	880	342	8·8	39	26·6	319	39 867	4 527
1974	800	613	16·1	76	27·7	584	75 665	4 699

[a] Mortality caused by shortage of oxygen
[b] Mortality caused by red water
[c] Mortality caused by growth of toxic algae

threefold in nine years (Fig. 6). On the other hand, the amount of feed used has only increased by a factor of about 2·5. As a result, the conversion ratio of this farm has gone down from 15:1 in 1966 to 10:1 in 1974.

In improving culture techniques, some serious problems about feed arose. One of these was the shortage of raw or natural feed. Another was its high cost and the tendency for its price to increase at a more rapid rate year by year, this becoming especially pronounced after 1972. Among the raw feed materials, the price increases for shortnecked clams and small shrimps were very rapid (Table V).

Table VI shows the changes in the composition of raw feed at Ube Kuruma-ebi farm. The proportion of shortnecked clams used was not so high either in quantity or value in the seventies, but it is believed that the growth of Kuruma-ebi is seriously affected if some proportion of clams is not used. During 1974, the price of shortnecked clams shot up rapidly, and the culturists stopped buying them. In 1975, the price of this clam rose even more rapidly, and most farms stopped using them altogether.

It was very fortunate, therefore, that when the prices of raw feed started increasing, artificial feed was introduced in the Kuruma-ebi culture industry. Owing to competition, the price of artificial feed has shown a tendency to decrease. Besides this economic competition, there has also been progress in the manufacturing technology for the new type of feed. If the price of one of the ingredients goes up, the manufacturers can replace it with another cheaper material without losing feed efficiency. At the Ube Kuruma-ebi farm, artificial feed is already important in terms of total feed used. It is said that a serious drawback of artificial feed is the difficulty of producing a fine red colour in the Kuruma-ebi. However, it should not be too great a problem to improve artificial feed so that it imparts a natural tint to the cultured Kuruma-ebi. Alternatively, another way to produce the red coloration in Kurima-ebi is to feed them with natural raw feed just before shipment.

There are many advantages in using artificial feed: (*i*) it helps keep the ponds in good condition, especially in the critical period during summer; (*ii*) it is easy to buy and store; (*iii*) the growth rate of Kuruma-ebi with artificial feed is the same as with raw feed; (*iv*) its price at present is almost the same as that of raw feed, and is expected to be stable in the future; and (*v*) unlike raw feed, its supply is not limited.

The last two points are especially important. One of the reasons that Kuruma-ebi culture farms were originally established in the Seto Inland Sea area was the availability of abundant natural feeds. At that time, there was little demand for low-class marine products for human consumption, their price was practically nil, and the culturists could freely use such materials as feed. But since then the number of shrimp farms has increased. The price of natural feeds may be cheap at times when the resources are greater than the demand for them. However, when the demand for feed reaches the limit of supply of natural feeds, their price rises rapidly. Unfortunately, the supply of shortnecked clams has been reduced by reclamation of coastal areas. Moreover, the demand for natural feeds has increased rapidly due to the expansion of Amakusa Kuruma-ebi culture as well as the increase in human consumption.

Culturists in the Seto Inland Sea and Amakusa areas will certainly find it very difficult to continue shrimp culture in the future without the use of artificial feeds. Although originally developed primarily for an intensive type of culture (in order to prevent deterioration of water quality

TABLE V
CHANGES IN FEED COST (PER KG) OF KURUMA-EBI (UNIT YEN)[1]

Year	*Average*	*Shortnecked clams*[2]	*Low quality shrimps*	*Other feeds*[3]	*Artificial feed*
1966	39·2				
1967	35·6				
1968	45·3				
1969	55·4				
1970	63·7				
1971	69·3	107·6	75·0	49·4	
1972	70·1	104·5	66·7	55·6	
1973	85·6	104·0	92·3	63·8	
1974	90 3	124·0	90·3	63·4	121·2
1975	116·2	186·0	120·1	60·0	116·0

[1] Data from Ube Kuruma-ebi Yoshokujo. Excludes the costs of transportation and storage.
[2] Clam meat only, excluding shell.
[3] Mainly mussels or imported lower-quality oysters

TABLE VI
CHANGES IN THE COMPOSITION OF FEED AT THE UBE KURUMA-EBI FARM (TYPE B)

	1971	*1972*	*1973*	*1974*	*1975*
Amount of feed used (tons)	*147*	*156*	*133*	*184*	*225*
Quantity:					
Total %	100·0	100·0	100·0	100·0	100·0
Low-quality shrimps	42·7	43·8	49·2	60·5	55·6
Shortnecked clams	15·5	19·6	20·8	10·4	—
Others	41·8	36·6	30·0	21·6	5·3
Artificial feed	—	—	—	7·5	39·1
Value:					
Total %	100·0	100·0	100·0	100·0	100·0
Low-quality shrimps	46·2	41·7	52·4	60·5	57·5
Shortnecked clams	24·0	29·3	25·2	14·4	—
Others	29·8	29·0	22·4	15·1	2·8
Artificial feed	—	—	—	10·0	39·7

and to promote the growth of the shrimps reared at high densities) the new artificial feeds are starting to be adopted for extensive and semi-intensive types of culture. Farms in areas seriously affected by the shortage and high price of raw feeds have been given the means of recovery.

5 General conclusions concerning shrimp culture

The shrimp culture industry in Japan has developed as the result of special economic and technical conditions.

(*i*) The price of live cultured shrimps is abnormally high because they are considered to be of exceptionally high quality compared with dead wild shrimp from capture fisheries.

(*ii*) This high price enables culturists to adopt intensive culture methods which involve a heavy capital investment and high production costs per kg of market-size shrimp. Owing to the high cost of land, the area of individual ponds is probably relatively smaller than it might be in most other countries. Therefore, in order to maximize their profit, Japanese aquaculturists try to rear shrimps at the highest possible densities. As a result, high mortalities commonly occur in their ponds. Good profits can be made, however, if high mortalities can be avoided during the critical periods. The same element of speculation or gambling can be found in all Japanese aquaculture. In such a situation, the most important technique is how to prevent high mortalities.

Some general comments can be made about shrimp culture in other areas based on this Japanese experience.

(*i*) The first important consideration is securing enough seed at a low cost. In our research, Type D and E farms did not have to buy their seed as they produced them in their own hatcheries. Seed stock which was surplus to their own requirements was sold to other farms. The Type A-C farms buy their seed from local governmental and private hatcheries. In this case, the cost of seedlings is very low.

In tropical or subtropical areas, especially in Asia, there are many fish farms, but few of these have specialized in shrimp culture due to the difficulty of getting enough seedlings. In the case of ponds used for the culture of milkfish (*Chanos chanos*), shrimp seedlings enter the ponds with the influx of sea water; and even in culture ponds specialized for shrimp, there is still a dependence on individual fishermen to catch seedlings in estuaries. Therefore, the amount of seedlings varies greatly every year, and instability of seedling supply has hindered the development of shrimp culture in both types of pond in these areas. Through artificial hatching, seedlings can be supplied at a low cost and, therefore, it would be advisable to build hatchery centres with the help of government funds.

(*ii*) The next point of consideration is maintenance of good water quality; scientific aquaculture can be said to start with water control. As mentioned in this review, the system of water exchange determines the type of culture and the type of culture determines the production per man and per unit area. Moreover, the type of culture depends on economic and geographic conditions in relation to the behaviour of shrimps.

(*iii*) A third consideration is feeds. High production can be obtained using feed, but the cost is high, especially if commercial feed is used. The first problem to be considered is how to make best use of natural productivity. The presence of natural food in the ponds is an important factor even in the more intensive types of culture. When using commercial feed, the production per man and per unit area increases to a high level, but expenditures are also increased. In view of this high cost, cultured products usually cannot compete with natural products caught by fishing where they both have the same price level. Therefore, shrimp farms using commercial feed can be economically viable only in special circumstances, *eg*, when there is a lack of production by fishing, or when special market conditions exist.

(*iv*) A final consideration is the selection of suitable kinds of shrimp for culture, for although many varieties are suitable for culture, only a few species are usually available in a particular area.

In conclusion, the importance of practical field surveys prior to initiating a shrimp culture project is emphasized. The technical and economic situation in each area should be determined as a basis for further development.

6 Appendix

Hasegawa's Formula[1]

In order to manage their business successfully, culture farms must be able to conform to the following simple relationship:

$$A \geqq \frac{N}{W} \tag{1}$$

where A = Selling price of commercial-size fish per kg
N = Total cost
W = Total cost of feed used.

From (1)
$$A \geqq \frac{N.a}{W.a} \tag{2}$$

where a = Conversion ratio from feed to fish

From (2)
$$\frac{A}{B} \geqq \frac{N.a}{W.a.B} \tag{3}$$

where B = Price per kg of feed

Then, $W.a.B$ is the total cost of feed used, and $\frac{W.a.B}{N}$ is the ratio of feed cost to total cost. Next, to simplify formula (3), we take $\frac{W.a.B}{N}$ as b.

Therefore $\frac{A}{B} \geqq \frac{a}{b}$

[1] Hasegawa, A. Price condition of marine culture industry. *Gyogo Kenzai Kenyu Fish.* 1963 *Econ. Tokyo,* 12(2)

The Culture of Freshwater Prawns: A Review

S. W. Ling and T. J. Costello

Abstract

Modern freshwater prawn culture has a developmental history of less than 15 years, but has already generated worldwide interest. Research and development projects have been initiated in most Asian countries, in North and South America, Europe, Africa and in several territories of Oceania and Micronesia.

Rearing experiments have been conducted with several of the larger species of prawns, but the giant Asian prawn, *Macrobrachium rosenbergii*, is most popular for experimental farming.

The systems of culture, the facilities, and the rearing techniques used, are basically those used in existing fish-farming systems. In the various facilities, there is a wide range of technological sophistication. Most of the commercial prawn farms are open pond systems, extensive in area and moderate in technological advancement. Some experiments with intensive closed-system rearing are in progress, but these are in the early experimental stages.

Methods for rearing larvae from eggs to juveniles are well developed, and large-scale production of 'seed' prawns is routine in several countries. The survival rate of larvae is highly variable from facility to facility.

Grow-out farms ordinarily use open earthen ponds, but some raceways and a few closed-system facilities are in operation on an experimental basis. In Asia, freshwater prawns are frequently cultured together with non-carnivorous fish in both fresh water and in brackish water of low salinity.

In many areas, the market demand for prawns is increasing rapidly, and present pond production will not satisfy anticipated demand. There is very little definitive information on the economics of prawn farming.

In the United States, and in several other countries, research is in progress to improve the efficiency of culture, increase production, and improve prawn stock quality.

Examen de l'élevage des crevettes d'eau douce

Résumé

L'élevage moderne des crevettes d'eau douce se pratique depuis moins de quinze ans, mais il suscite d'ores et déjà l'intérêt dans le monde entier. Des projets de recherche et de développement ont été mis en œuvre dans la plupart des pays d'Asie, dans les deux Amériques, en Europe, en Afrique et dans plusieurs territoires de l'Océanie et de la Micronésie.

Des expériences d'élevage ont porte sur plusieurs des plus grandes espèces de crevettes, mais l'espèce la plus populaire aux fins de culture expérimentale est la crevette asiatique geante, *Macrobrachium rosenbergii*.

Les modes de culture, les installations et les techniques d'élevage utilisés sont essentiellement ceux qui servent dans les systèmes de pisciculture actuels. Les installations correspondent à divers stades d'évolution technique. La plupart des élevages commerciaux de crevettes sont des systèmes d'aquaculture en étangs à ciel ouvert, utilisant une superficie extensive et des techniques assez peu évoluées. Quelques expériences d'élevage intensif en système clos sont en cours, mais elles en sont aux stades initiaux.

Les méthodes d'élevage des larves depuis les œufs jusqu'aux juvéniles ont fait des progrès substantiels, et la production de géniteurs est pratiquée sur une base de routine en plusieurs pays. Le taux de survie des larves varie considérablement d'une installation à l'autre.

Les fermes de croissance utilisent généralement des étangs en terre. A l'heure actuelle, quelques raceways et systèmes clos fontionnent sur une base expérimentale. En Asie, on élève fréquemment les crevettes d'eau douce en même temps que des poissons non carnivores, tant dans l'eau douce elle-même que dans une eau saumâtre à faible salinité.

En de nombreuses régions, la demande de crevettes augmente rapidement, et la production actuelle des étangs ne saurait satisfaire aux besoins escomptés pour l'avenir. L'on a très peu de renseignements définitifs sur l'économie des élevages des crevettes.

Aux Etats-Unis et en plusieurs autres pays, des recherches sont en cours pour améliorer l'efficacité de l'élevage, accroître la production et rehausser la qualité des stocks de crevettes.

El cultivo de camarones de agua dulce: una revisión

Extracto

El cultivo moderno de camarones de agua dulce, a pesar de contar con menos de 15 años de historia, ha despertado ya interés en todo el mundo. Se han iniciado proyectos de investigación y desarrollo en casi todos los países de Asia, en América del Norte y del Sur, Europa, Africa y varios territorios de Oceanía y Micronesia.

Se han realizado experimentos de cría con varias de las especies de camarones de mayor talla, pero la especie más popular para la cría experimental es el camarón gigante de Asia *Macrobrachium rosenbergii*.

Los sistemas de cultivo, las instalaciones y las técnicas de cría son fundamentalmente las mismas que se utilizan en piscicultura. Según el tipo de instalación, las técnicas pueden ser más o menos complicadas. La mayor parte de las explotaciones dedicadas a la cría comercial de camarones consisten en un sistema de estanques en circuito abierto, de gran superficie y moderada sofisticación tecnológica. Se están realizando algunos experimentos de cría intensiva en circuito cerrado, pero se encuentran aún en las primeras fases.

Los métodos de cría de larvas desde la incubación hasta la fase juvenil están muy avanzados y la producción a gran escala de camarones para 'semilla' es ya cuestión de rutina en muchos países. El índice de supervivencia de las larvas varía muchísimo según las instalaciones.

Las granjas de cultivo de camarones comerciables utilizan de ordinario estanques de tierra en circuito abierto. Actualmente funcionan con carácter experimental algunos canales de cría e instalaciones en sistema cerrado. En Asia, los camarones de agua dulce se cultivan con frecuencia junto con peces no carnívoros en aguas dulces y en aguas salobres de baja salinidad. En muchas zonas, la demanda de mercado de los camarones aumenta rápidamente y la producción actual de los estanques no será suficiente para atender la demanda prevista en el futuro. Es muy poca la información definitiva existente sobre los aspectos económicos de la cría de camarones.

En los Estados Unidos y en otros varios países se están realizando investigaciones para mejorar la eficiencia del cultivo, aumentar la producción y mejorar la calidad de las poblaciones de camarones.

1 History of development

Culture of freshwater prawns from eggs spawned artificially is a recent development—the first successful rearing occurred less than 14 years ago, and commercial prawn farming is only in the early stages of development.

Primitive methods of prawn culture have, however, been practised for centuries in some Asian countries, especially India and Bangladesh. These are the traditional 'trapping-holding-growing' operations, in which young prawns (from wild stocks) are introduced into ponds, tanks, paddy-fields, and 'Bheris', and held in these enclosures to feed and grow to edible size.

Following the second world war, the need for increased production of food prompted interest in the revival of old and the development of new aquacultural practices in most Asian countries. Most of these aquacultural developmental activities were directed to finfish culture, while prawns received minor attention. At first, studies on freshwater prawns were mainly restricted to the natural history, general biology, habits, and life history of the economically important species. Early attempts to raise prawns by stocking ponds with juvenile prawns collected from their natural habitats had disappointing results. For a number of years, experiments in several Asian countries on the rearing of prawn larvae to juveniles under controlled conditions were unsuccessful. In 1961, a major breakthrough was made at the Marine Fisheries Research Institute, Penang, Malaysia, when it was discovered that a certain amount of salinity was an important basic requirement for *Macrobrachium rosenbergii* larvae to survive and develop through their early life stages.

Following this discovery, techniques for rearing new hatchlings through all their larval stages were developed. The first juvenile prawns were produced in June 1962. In the spring of 1963, sufficient numbers of juveniles were produced to initiate grow-out experiments in ponds. Since fish culture was popularly practised in Malaysia, and fish farmers were experienced in various aspects of fish farming including pond management, the use of prawns for pond culture was readily accepted there.

News of success in rearing larvae to juveniles and in culturing juveniles to large prawns spread rapidly. Within a period of about ten years, worldwide interest in freshwater prawn culture was generated and research and development

projects started in practially all the Asian and Far Eastern countries, several territories in Oceania and Micronesia, several North and South American countries, and some countries in Africa, Europe and in the Middle East.

Malaysia, the birth place of *Macrobrachium* culture, is still the leading Asian country in this field of development. In Hawaii, prawn culture research was initiated in 1965 with a brood stock of *M. rosenbergii* imported from Malaysia. Based on techniques developed in Penang, within less than three years the Hawaiian project has achieved many major improvements of old and development of new practical techniques for mass production of juveniles and commercial-scale prawn farming. Hawaii has become an international centre of research, demonstration and training on *Macrobrachium* prawn farming.

2 Present status

2.1 *Species cultured*

The term 'freshwater prawn' is here used in a broad sense, covering both the species that spend their entire life cycle in fresh water, as well as those that spend part of their life cycle in fresh water and part in saline water.

A list of those species currently utilized in the research and development of prawn farming is given on page 301.

As shown in the list, all the prawns that are utilized in one way or another for prawn culture development belong to the family, Palaemonidae; a few belong to the genera *Leander* and *Palaemon*, but the majority belong to the genus *Macrobrachium*. All species of *Leander* and *Palaemon* experimented are small in size, have a slow growth rate and are not considered economical for commercial farming.

Among the dozen or so species of the genus *Macrobrachium* experimented on, most of the large and medium size species—*M. acanthurus, M. americanum, M. carcinus, M. lar, M. malcolmsonii, M. ohione* and *M. rosenbergii*–show potential for prawn farming development.

The Indian species *M. malcolmsonii*, is quite similar in size and habit to the American species, *M. carcinus*. *M. lar* is an active climber and traveller, requires a high content of dissolved oxygen, is rather cannibalistic and is difficult to keep in enclosures.

M. lanchesteri of Malaysia, known as the paddy-field prawn because of its ability to live in fresh waters throughout its life cycle, grows rather rapidly and in crowded conditions, has high tolerance to wide ranges of water temperature, oxygen content, and organic pollution, is not carnivorous, is non-cannibalistic, and is regarded as having a good potential for farming (Johnson, 1969), especially in Asia where medium size shrimps and prawns are appreciated, and bring a fairly high market price.

To date, however, the best known and most popular species used is *M. rosenbergii*, not only because most of the pioneering prawn culture work was done on this species, but because of its comparatively tame and less cannibalistic behaviour, fast growth rate, shorter larval period and higher tolerance to a wider range of temperature and salinity.

The spread of *M. rosenbergii* for research and culturing is worldwide. Japan and Singapore obtained their original stock from Malaysia. Taiwan Province of China imported its stock from Thailand, while Bangladesh, Burma, India, Indonesia, Kampuchea, Malaysia, Philippines, Sri Lanka Thailand and Viet Nam all have their own native stock. Australia and England obtained some stock from Malaysia. Israel's came from Thailand. Hawaii obtained its original stock from Malaysia in 1965 and the handful of survivors became the great grandparents of the progeny that have spread directly or indirectly to many parts of the USA as well as to Mexico, Jamaica, Puerto Rico, Honduras, Colombia and other Latin American countries for experimental work and commercial farming. Only recently have limited numbers of broodstock (mostly wild stock) from other Asian countries been imported to the New World, mainly for stock improvement experiments.

2.2 *Hatchery operation and rearing of juveniles*

Techniques for raising larvae from eggs to juveniles are fairly well developed for *M. rosenbergii*, and these methods are used as a basis for rearing other *Macrobrachium* species. Differences in environmental conditions, socio-economic backgrounds, and the degree of development of laboratory systems are manifest when comparing *Macrobrachium* rearing laboratories in different parts of the world. Some of the more simply operated facilities are the most effective. Nearly all laboratories, experimental stations, and hatcheries involved in prawn research are able to produce some prawn juveniles from eggs, and a few are able to produce juveniles in commercial quantities. Apart from government experimental stations, several private prawn hatcheries are already in active operation in Thailand, Taiwan Province of China, and Malaysia. The system of operation used is moderately advanced, but leaves considerable room for improvement.

2.2.1 *Facilities*

(*i*) For holding breeding stock of various sizes, outdoor earthen ponds and cement and fibreglass tanks housed in roofed sheds are used.

(*ii*) For incubation and hatching of eggs, medium-size aquarium tanks are mostly used.

(*iii*) For rearing larvae, large aquarium tanks, earthenware jars, cement tanks or troughs, plastic tanks, and fibreglass tanks of various sizes have been used by different laboratories for experimental purposes. For large-scale operations, large cement tanks are popularly used. These are ordinarily rectangular in shape in a wide range of sizes, typically 3–8 m × 1–2·5 m and 0·5–1·0 m deep. Practically all of these larval rearing tanks are housed in roofed sheds. All larval rearing tanks are provided with water aerators, agitators, and circulation and filtration devices.

(*iv*) For rearing juveniles, large rectangular cement tanks housed in roofed sheds are most frequently used. Juveniles are held in these tanks until they reach 1–2 g in size before being placed in outdoor growout ponds. The size at which juveniles are placed in grow-out ponds varies a great deal.

2.2.2 *Water supply.* Difficulties in obtaining unpolluted sea water have been experienced by practically all the prawn laboratories and hatcheries in Asia. The problem of supplying good clean sea water has become a major constraint in the development of commercial-scale production of juveniles. At present, large tanks are used to store sea water and filtration and sterilization units are installed to treat sea water before use.

2.2.3 *Breeding stock and berried females.* Most of the laboratories and hatcheries maintain breeding stock, from which they obtain their supply of berried females. By

Species	*Countries or areas used for experiments or culture*	*Extent of development**
Leander fluminicola	India	A, B—well advanced
L. styliferus	India	A, B—well advanced
Palaemon lamarrei	India	B—advanced
P. serratus	North Wales (UK)	B—well advanced
		C, D—experimental
	France	B—completed
		C, D—experimental
Macrobrachium acanthurus	USA	B—well advanced
	Mexico	C, D—experimental
M. amazonicum	Brazil	B, C—experimental
M. americanum	Central and South America	A, B—advanced
		C—experimental
M. carcinus	USA	A, B—well advanced
		C, D—experimental
	Puerto Rico	A—advanced
		C, D—experimental
	Barbados	B—well advanced
		C, D—experimental
M. tenellum	Colombia	D—experimental
M. formosense	Okinawa (Japan)	B—well advanced
M. lanceifrons	Philippines	A, B—advanced
M. lanchesteri	Malaysia	A—advanced
M. lar	Malaysia	A—in progress
	Taiwan, Province of China	A, B—in progress
	Hawaii (USA)	A, B—advanced
		C—in progress
	Tahiti	A—advanced
M. malcolmsonii	India	A, B—well advanced
		C, D—experimental
	Bangladesh	C, D—experimental
	Pakistan	C, D—experimental
M. modestus	Japan	A, B—well advanced
M. nipponense	Japan	A, B—well advanced
M. ohione	USA	A, B—well advanced
		C, D—experimental
M. rosenbergii	Australia	C—successful
		D—pilot scale
	Bangladesh	B—started
		C, D—experimental
	Burma	B—started
		C—experimental
	Kampuchea	C—experimental
	India	A, B—completed
		C, D—experimental
	Indonesia	C, D—experimental
	Japan	B—successful
		C, D—experimental
	Taiwan, Province of China	C—large scale
		D—moderate
	Malaysia	C—large scale
		D—moderate
	Philippines	B—completed
		C—started
	Singapore	C—moderate
		D—pilot
	Sri Lanka	B—completed
		C—started
	Thailand	C—large scale
		D—experimental
	Viet Nam	C—experimental
	Polynesia	C—large scale
		D—pilot scale
	Palau	C, D—experimental
	Tahiti	C—large scale
		D—pilot scale
	Mauritius	C—moderate
		D—experimental
	Seychelles	C—small scale
		D—experimental
	Malawi	C—small scale
		D—experimental
	Hawaii (USA)	C—large scale
		D—successful commercial farms
	USA	C—large scale
		D—moderate
	Mexico	C—experimental
		D—experimental
	Puerto Rico	C—large scale
		D—large commercial farm
	Honduras	C—large scale
		D—large commercial farms
	Colombia	C—experimental
		D—experimental
M. rude	Thailand	A—in progress

* Symbols of extent of development: A = Field biology studies; B = Laboratory life-history studies; C = Production of juveniles; D = Growout operation

keeping a stock of about 400 mature females and 100–150 males, an average of about 40 berried females will be available each week for most of the year. In Asia berried females are only occasionally obtained from their natural habitats. Old, weak or injured specimens are removed from time to time and replaced by healthy, large specimens obtained from the grow-out ponds.

Breeding stock is reared in either fresh or slightly brackish water (salinity range 2–8 ppt). These are fed mussels, cockles, fresh trash-fish or compounded fish feed, whichever is readily available cheaply.

2.2.4 *Incubation and hatching of eggs.* For incubation and hatching, berried females are held in ordinary aquarium tanks or any suitable small receptacles, or even directly in the larval rearing tank. Berried females carrying eggs which were all spawned within a 5 day period are selected and kept in the same tank so that the eggs will all hatch within 4–5 days of each other. This minimizes size differences and possible predation or cannibalism.

Eggs can be incubated in fresh or brackish water; common practice is to use water with a salinity of 6–12 ppt. When incubation and hatching is carried out directly in larval rearing tanks, the salinity of the water is the same or slightly lower than that intended for rearing larvae.

2.2.5 *Rearing larvae*

(*i*) Maintenance of water conditions: Favourable water conditions are maintained by regulated water aeration, agitation and filtration. Salinity in the rearing facilities is maintained within a range of 12–16 ppt, pH about 7·5–8, temperature 26–30°C and depth 0·5 m.

To minimize water pollution, uneaten food materials and larval wastes which accumulate at the bottom are removed daily by siphoning. To avoid loss of larvae through siphoning, they can be concentrated at one end of the tank by shading. The water is partially changed one or two times a week by removing the bottom $\frac{1}{3}$ or $\frac{1}{4}$ and replacing it with newly prepared water of similar salinity.

(*ii*) Density of larvae: the density of larvae is maintained at about 100–150/l in the initial stages. Losses occur at each stage of development so with no modification in the volume of water in the larval rearing tank, densities may typically reach 20–60/l toward the end of the larval rearing period. Sick and Beaty (1974), in a series of well designed experiments, found stocking densities of 40 animals/l best, considering growth and survival rates.

(*iii*) Food and feeding: *Macrobrachium* larvae have been successfully reared on a wide variety of foods. The present trend in Asia is to minimize the use of brine shrimp (*Artemia*) nauplii because their eggs are all imported and have become increasingly expensive and difficult to obtain. Brine shrimp nauplii are now being used primarily during the first week of larval rearing, after which a variety of specially prepared foods available locally at low cost are substituted. Foods found to be useful are: rotifers, cyclops, other copepods, daphnids and other small entomostracans; fish eggs, and small pieces of animal and plant material such as aquatic worms, mussels, cockles, clams, squids, insect larvae, mysids, *Acetes*, other small crustaceans, fish, steamed egg custard, grain, beans and soy custard. Live food of suitable size is the preferable diet for larval prawns. However, material such as mullet roe may be used fresh or stored frozen for extended periods (the eggs of mullet roe can be easily separated from the ovary when the roe is thawed in water). Small entomostracans, *Acetes*, and small shrimps are often kept in a freezer for use during the off season. Steamed egg custard and soy bean curd are readily ingested by the larvae, and because of their high protein content, easy availability and cheap price, are gaining in popularity as larval feed.

(*iv*) Prevention and control of larval mortality: High mortality of larvae has been experienced in most laboratories and hatcheries. The principal methods for preventing mortality are: (*i*) maintenance of suitable water quality and environmental conditions; (*ii*) provision of food quality and sufficient quantity of food and adequate frequency of feeding; (*iii*) removal of polluting material; (*iv*) disinfection of tanks and equipment and sterilization of water; and (*v*) screening of water to prevent entry of predators.

Occurrence of disease and parasites have also been encountered, but no effective control measures for these have been developed.

2.2.6 *Rearing of juveniles.* Newly metamorphosed juveniles are usually allowed to remain in the larval tanks for 1–2 weeks before being transferred to juvenile (nursery) tanks. Water in these juvenile tanks is maintained at very low or no salinity, is well aerated and maintained at depths of 0·3–0·5 m.

Material suitable for feeding juveniles include: small pieces of fish, shrimps, *Acetes*, chironomid larvae, squid, mussel, cockle, worms, grains, beans and high-protein compounded pellets.

In Thailand, Malaysia and Indonesia, juveniles and young prawns are sometimes collected from their natural habitats for growing in ponds. In Thailand there is an extensive industry collecting young juveniles below dams for stocking and growout above the dams.

2.3 *Status of prawn farming in Asia*

2.3.1 *Grow-out operation (growing juveniles to edible size)*

(*i*) System of farming: most of the prawn farming operations are still experimental or conducted at pilot-scale level. The basic techniques used are mainly the existing fish culture methods practised extensively in Asia for many years. In general, the system used is one of open ponds, extensive in area, fairly labour intensive, moderately mechanized, and involving little modern technology.

(*ii*) Ponds: most of the ponds used for prawn culture are converted from existing fish ponds, with some alteration and improvement; often even new ponds are constructed similar to the traditional type of Asian fish ponds. These are all earthen ponds, mostly rectangular in shape, 1 000–5 000 m^2 in area, 1–2 m in depth and provided with efficient water supplies, drainage systems and water sluice gates. Water aerators and water agitators are sometimes installed in the ponds.

(*iii*) Water supply: fresh water is mainly used for farming prawns in Asia, but prawns also grow well in brackish water of a salinity up to about 10 ppt. Fresh water may be supplied from a well, river, stream or irrigation system. City water is seldom used. Brackish water is obtained, during high tide, from tidal canals or from an adjacent estuarine area.

(*iv*) Preparation of pond for stocking: preparation of a pond for stocking prawns follows similar techniques and

procedures similar to those used for preparing fish ponds. These are: (*a*) complete draining and drying of the pond (whenever possible); (*b*) levelling of the bottom, mending of embankment, repair of water sluice gates and water supply and drainage system; (*c*) application of lime and fertilizers, and (*d*) introduction of water into the pond.

(*v*) Stocking: to ensure good survival, juveniles 2–4 weeks old (from time of metamorphosis) are used for stocking.

Prawns are ordinarily cultured alone, but the practice of culturing prawns together with non-predatory fish such as the grass carp (*Ctenopharyngodon idella*), silver carp (*Hypophthalmichthys molitrix*), bighead carp (*Aristichthys nobilis*), and grey mullet (*Mugil cephalus*) has been successfully demonstrated and is gaining popularity among Asian fish farmers.

The rate of stocking in Asia depends on: (*a*) whether the prawns are to be cultured alone or in combination with suitable species of fish; (*b*) if they are cultured with fish, the kinds and number of fish to be stocked; (*c*) water quality and pond soil fertility; (*d*) kinds and quantity of fertilizers to be used, and (*e*) quality and quantity of available feeds. For culturing in combination with fish, a stocking rate of 5 000–15 000/ha is generally used; when cultured alone, about 15 000–30 000/ha. This stocking rate in Asia is considerably less than the stocking rates used at recently developed grow-out facilities in Hawaii, Puerto Rico, Honduras and Panama, but commensurate with the practice in Asia to supply minimal amounts of supplemental food.

(*vi*) Feed and feeding: prawns depend a great deal on the food material produced in the pond. Supplemental feeds are given only in moderate quantity. When cultured in combination with high densities of fish, prawn often make use of the fish feeds and so little or no supplemental feed is given to the prawns. Material used as prawn feeds are: trash fish or any non-oily inexpensive fish, small shrimp, mussels, squid, corn, peanut cake and soybean cake.

(*vii*) Pond management: to minimize the danger of oxygen depletion, a gentle flow of water is maintained, especially at night; whenever possible, ponds are provided with good aerators or water agitators. A few grass carp and silver carp are often stocked (when prawns are cultured alone) to help control excessive growth of aquatic plants and phytoplankton. Water inlets are screened to prevent predatory fish and their eggs and young from entering the ponds and also to prevent escape of the prawns.

(*viii*) Prevention and control of predators, competitors, diseases and parasites: methods for the prevention and control of predators, competitors, disease and parasites are mainly the existing practices popularly used in fish farming operations. Draining, drying and liming of a pond prior to stocking is effective in killing the spores, eggs and young stages of many predators, and disease-causing organisms, parasites and competitors. Some diseases and parasites have been observed, but due to the lack of trained personnel in this field, there has been little research on their diagnosis, prevention and control.

(*ix*) Harvesting: two principal harvesting systems are followed, partial and complete. Partial harvesting consists of a system for removing the larger prawns from a pond at regular, often monthly, intervals. This is accomplished with a specially designed seine net which will capture the larger prawns and allow the smaller ones to escape. In some areas, a seine with smaller mesh may capture most of the prawns in a pond. The larger prawns are then selected for market and the smaller ones returned to the pond.

A complete harvest is accomplished at the end of a culture cycle by draining the pond and concentrating prawns in a small pit near the pond drain.

2.3.2 *Marketing, handling and processing.* The popularity of the prawn among consumers—homes, restaurants, hotels, airlines, ocean liners, *etc*—continues to increase, causing a steady increase in market demand. The wild stock which is still the principal source of supply is decreasing steadily, while the production from the young prawn farming industry is very small, representing only a small fraction of the quantity needed to satisfy the domestic market in Asia, let alone the international market.

The domestic demand for fresh prawns is so great that prawns harvested from ponds are quickly absorbed by local markets. Ordinarily, prawns are harvested, sent to the market early in the morning, and sold within a few hours. Most of them are kept fresh under ice flakes; some are kept alive in tanks or cisterns with running water, or in shallow bamboo baskets covered with fine aquatic plants and kept moist and cool by frequent sprinkling with ice-cold water.

Prawn heads are well liked by southeast Asian people so prawns are always sold heads-on in domestic markets in Asia.

Up to the present, all prawns exported from Asia were wild stock caught from open waters, or from trapping-growing enclosures. They are headed, de-veined and frozen like processed penaeid shrimp.

2.3.3 *Economics of prawn farming.* Little reliable information is available on the economics of prawn farming in Asia and the Far East. In general, in most of the developing countries, where large areas of inexpensive land are available, labour is comparatively cheap, but financial resources are poor. The tendency is to adopt a less sophisticated and consequently less expensive system of operation. Though the yield per unit area may be comparatively small, the cost of production is low enough to be economically profitable.

2.4 *Freshwater prawn culture in the Americas*

Development of prawn culture in the Americas began in Hawaii in 1965 with the importation of 36 giant freshwater prawns, *Macrobrachium rosenbergii* from Malaysia. Under the leadership of Takuji Fujimura, a prawn culture industry has developed in the Hawaiian islands. Fujimura and his associates have also provided the principal expertise which has led to the development of prawn culture facilities elsewhere in the Americas. There are at least 19 facilities in the Americas farming *Macrobrachium* or developing techniques designed to improve systems for prawn culture. The larger grow-out facilities are located in Panama, Honduras, Puerto Rico, Texas, Florida and Hawaii. Some of these facilities are presently producing substantial quantities of prawns, which are being test marketed in the United States.

In addition to the production of pond-reared prawns in Panama, Honduras, Puerto Rico and Hawaii, several companies are attempting to develop closed system processes to rear commercial quantities of prawns in an entirely synthetic environment. To date none of these has produced any substantial quantities of prawns for the market, and information on most of their progress and development is proprietary. It is considered that it will require several years

to prove or probably disprove the economic feasibility of closed systems to rear prawns for market. Few culturists doubt the present capability to rear prawns in closed systems, but considering cost factors it is difficult to foresee how this can be a profitable system in the near future.

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Culture of Freshwater Shrimps in Fertilized Ponds

L. A. Guerrero and R. D. Guerrero III

Abstract

Few studies on the culture of shrimps capable of reproducing in freshwater ponds are reported. Preliminary experiments to evaluate *Macrobrachium lanchesteri* and *M. lanceifrons montalbanense* stocked with and without fish in fertilized ponds were conducted. Stocking ovigerous female and juvenile shrimps in four 0·1 ha earthen ponds with *Tilapia mossambica* and *T. nilotica* resulted in net shrimp production of 37 to 179 kg/ha after 90 days, indicating heavy reproduction of the shrimps. Shrimp standing crops of 384 and 391 kg/ha were obtained after 120 days in ponds stocked with adult male and female shrimps at rates of 10 and 9 kg/ha respectively. Pond production of freshwater shrimps has considerable potential and further studies are recommended on the biology, ecology and cultural management of *M. lanchesteri* and *M. lanceifrons montalbanense*.

Elevage de crevettes d'eau douce dans des étangs fertilisés

Résumé

Peu d'études sur l'élevage des crevettes susceptibles de se reproduire dans des étangs d'eau douce ont été publiées. Des expériences préliminaires visant à évaluer *Macrobrachium lanchesteri* et *M. lanceifrons montalbanense* placés dans des étangs fertilisés, en présence ou non de poissons, ont été réalisées. La mise en charge de quatre étangs en terre de 0,1 ha, par des femelles ovigères et des jeunes crevettes en présence de *Tilapia mossambica* et *T. nilotica* a entraîné une production nette de crevettes de 37 à 179 kg/ha en l'espace de 90 jours, ce qui indique une reproduction massive des crevettes. Des biomasses de crevettes de 384 et 391 kg/ha ont été obtenues dans des étangs peuplés de crevettes adultes mâles et femelles, à raison de 10 et 9 kg/ha respectivement, au bout de 120 jours. La production de crevettes d'eau douce dans des étangs offre de grandes possibilités et l'on recommande que des études plus poussées soient effectuées sur la biologie, l'écologie et les pratiques culturales de *M. lanchesteri* et *M. lanceifrons montalbanense*.

Cultivo de camarones de agua dulce en estanques fertilizados

Extracto

Son pocos los estudios conocidos sobre el cultivo de camarones capaces de reproducirse en estanques de agua dulce. Se han realizado algunos experimentos preliminares para evaluar el rendimiento de *Macrobrachium lanchesteri* y *M. lanceifrons montalbanense* en estanques fertilizados con peces y sin peces. Echando hembras ovígeras y formas juveniles de camarones en cuatro estanques de tierra de 0,1 ha con *Tilapia mossambica* y *T. nilotica* se obtuvo una producción neta de camarones de 37 a 179 kg/ha a los 90 días, lo que indica una intensa reproducción de los camarones. En estanques sembrados con camarones adultos, machos y hembras, a razón de 10 y 9 kg/ha, respectivamente, se obtuvieron al cabo de 120 días rendimientos de 384 y 391 kg/ha. La producción de camarones de agua dulce en estanques ofrece considerables posibilidades y se recomienda que se realicen nuevos estudios sobre la biología y ecología de *M. lanchesteri* y *M. lanceifrons montalbanense* y su explotación mediante cultivo.

1 Introduction

Little is known about the culture of small freshwater shrimps in ponds. The presence of *Macrobrachium lanchesteri* in ricelands and its ability to reproduce in stagnant fresh water were reported by Johnson (1968). Guerrero, Guerrero and Grover (1975) found substantial yields of *M. lanchesteri* and *M. lanceifrons montalbanense* in fertilized freshwater ponds with milkfish, *Chanos chanos*. Heavy predation of the shrimps by *Tilapia* species was noted.

Although smaller than the giant freshwater prawn, *Macrobrachium rosenbergii*, *M. lanchesteri* shows promise as an important animal protein resource for the rural masses of southeast Asia. *M. lanchesteri* breeds under pond conditions, is an algal feeder, and is not cannibalistic (Johnson, 1968). Because of these advantages, this mini-shrimp can be produced at a much lower cost than that for the giant prawn.

With meagre information on the pond culture of *M. lanchesteri* and *M. lanceifrons montalbanense*, which occur naturally in the irrigation canal of the Freshwater Aquaculture Center at Munoz and in some lakes of the Philippines, experiments were conducted from April to July 1975 to determine the feasibility of stocking ovigerous female and juvenile shrimps in fertilized ponds with *Tilapia mosambica* and *T. nilotica*, and to determine the production potential of the shrimps in ponds not stocked with fish.

2 Materials and methods

Six 0·1 ha earthen ponds were completely drained and refilled with water from a deep well. To prevent possible shrimp and fish contamination, their inlet pipes were doubly screened with 2 mm stretched mesh nylon netting. The ponds were poisoned with 25 ppb of Gusathion A seven days before stocking.

The shrimps used in stocking were collected from a breeding pond at the station. Two ponds were stocked with 0·40 kg and 0·31 kg of ovigerous female shrimps (0·4 g mean weight), respectively; two ponds were each stocked with 1·0 kg of juvenile shrimps (0·2 g mean weight) and two ponds with 1·0 kg and 0·90 kg of adult male and female shrimps (1·2 g mean weight), respectively.

Tilapia mossambica (0·1 g mean weight) were stocked at 10 000 and 15 200/ha in the two ponds with 0·40 kg ovigerous female shrimps and 1·0 kg juvenile shrimps, respectively. The two other ponds with 0·31 kg ovigerous female shrimps and 1·0 kg juvenile shrimps were stocked with *T. nilotica* (6 g mean weight) at 10 000 and 10 800/ha, respectively. No fish were stocked in the two ponds with adult shrimps.

Ten shrimp shelters made of bundles of *Tamarindus indicus* brush were placed in each pond stocked with fish. These shelters were approximately 1 m long and 30 cm in diameter. All ponds were fertilized with 16–20–0 (N–P–K) applied on platforms at 50 kg/ha every two weeks. Water depth in the ponds was maintained at 60–70 cm.

The four ponds stocked with fish and shrimps were drained after 90 days of culture. The other two ponds, stocked with adult shrimps only, were drained after 120 days. Fish and shrimp were harvested with scoop nets. The recovery rates of the fish and the standing crops of both fish and shrimps were measured.

3 Results and discussion

The data presented in Table I indicate that stocking of ovigerous female and juvenile shrimps in fertilized ponds with fish resulted in heavy reproduction of the shrimps. Net shrimp production ranged from 36·7 to 178·6 kg/ha in ponds with *Tilapia* species stocked at different weights and rates. Maturity of *M. lanchesteri* is attained in 28 days (Bui Shi Lang, personal communication). This relatively short life cycle and apparent prolific nature of the species could account for the massive production of shrimps. The proportions of *M. lanchesteri* and *M. lanceifrons montalbanense* in the populations harvested from ponds were not determined.

TABLE I
SUMMARY OF STOCKING WEIGHT AND STANDING CROP AT HARVEST OF FRESHWATER SHRIMPS AND *TILAPIA* SPECIES AFTER 90 DAYS

Pond number	*Species stocked*	*Weight stocked (kg/ha)*	*Standing crop (kg/ha)*
1	Shrimps[a]	4·0	179
	T. mossambica	10·0	540
2	Shrimps[a]	3·1	37
	T. nilotica	64·8	354
3	Shrimps[b]	10·0	91
	T. mossambica	1·5	542
4	Shrimps[b]	10·0	112
	T. nilotica	60·0	879

[a] Ovigerous females
[b] Juveniles

Stocking of adult shrimps only in ponds produced high yields after 120 days (Table II). One of the ponds was contaminated with 456 *Tilapia zillii* which presumably entered during the experiment.

Findings of the experiments suggest that there is considerable potential for culturing freshwater shrimps as a primary or secondary pond crop.

TABLE II
STOCKING WEIGHT AND STANDING CROP OF FRESHWATER SHRIMPS AFTER 120 CULTURE DAYS

Pond number	*Weight stocked (kg/ha)*	*Standing crop (kg/ha)*
5	10	384[a]
6	9	391

[a] Pond contaminated with *Tilapia zillii*

The lower production of shrimps in ponds stocked with *Tilapia* species as compared to ponds not stocked with fish was probably because of predation. An analysis of the stomach contents of tilapia showed the presence of larval shrimp remains.

Recovery rates of *T. mossambica* were 90 and 86%, and those for *T. nilotica* were 49 and 77%. Low recovery rates for *T. nilotica* were attributed to handling stress at stocking.

No valid relationships between fish and shrimp productions from the experiments can be established. Whether stocking of adult shrimps in ponds instead of ovigerous females or juveniles will yield higher productions is likewise not clear. However, shrimp harvests from the ponds consisted predominantly of juveniles.

Fertilization of the ponds produced blue-green algae blooms (eg, *Microcystis* sp.). In some ponds, *Elodea* sp. was abundant and made harvest of the shrimps difficult.

Freshwater shrimps have a higher market value than fish in the region. The shrimps can be sold fresh, dried or processed into shrimp flour and flakes. Further studies are therefore recommended on the biology, ecology and cultural management of these shrimps in ponds.

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Experimental Aquaculture of the Malaysian Prawn, *Macrobrachium rosenbergii*, in South Carolina, USA[1]

P. A. Sandifer and T. I. J. Smith

Abstract

The development and preliminary testing of a model system for the culture of *Macrobrachium rosenbergii* in South Carolina is presented. The model consists of four basic components: (*i*) indoor maintenance of broodstock for production of larvae (mid-October to May); (*ii*) production of post-larvae using a recirculating synthetic seawater hatchery system (mid-January to May); (*iii*) operation of closed system nursery tanks to rear post-larvae to larger juveniles for stocking in ponds (mid-February to May); and (*iv*) intensive pond cultivation of juveniles to marketable size (late April/May to mid-October).

Preliminary trials have demonstrated technical feasibility of the model. Brood prawns have been maintained over winter in closed system tanks; production of post-larvae has averaged 25/l of tank capacity in a laboratory-scale hatchery connected to a recirculating synthetic seawater system; post-larval prawns have been reared to juveniles at relatively high densities (to about 500/m^2) in tanks with good survival; and yields in the order of 1 000–2 000 kg/ha of pond are projected when juveniles of ⩾0·25 g are stocked. Major problems encountered in testing the model included the agonistic nature of *M. rosenbergii*; predation of larvae by a hydrozoan (*Moerisia lyonsi*) which became established in the hatchery system; and bacterial diseases. Priorities for future research include the design of efficient nursery systems, genetic manipulation to improve growth characteristics of the prawn and increase its tolerance to low temperatures, development of cost-effective rations, and identification or development of suitable markets.

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L'aquaculture expérimentale de la crevette malaise, *Macrobrachium rosenbergii*, en Caroline du Sud, E-U
Résumé
L'élaboration et l'expérimentation préliminaire d'un système modèle sont présentées pour l'élevage de *Macrobrachium rosenbergii* en Caroline du Sud. Le modèle se compose de quatre éléments de base: (*i*) conservation sous abri de stocks de géniteurs, en vue de la production de larves (mi-octobre à mai); (*ii*) production de post-larves en utilisant un système de recyclage d'eau de mer synthétique dans des écloseries (mi-janvier à mai); (*iii*) utilisation de réservoirs en circuit fermé pour l'élevage des post-larves jusqu'aux stades juvéniles en vue de la mise en charge des étangs (mi-février à mai); et (*iv*) élevage intensif de juvéniles en étangs jusqu'à ce qu'ils atteignent une taille commerciale (fin avril/mai jusqu'à la mi-octobre).

Des essais préliminaires ont démontré les possibilités techniques du modèle. Des crevettes destinées à la reproduction ont été maintenues pendant l'hiver dans des réservoirs en circuit fermé. La production des post-larves a été en moyenne de 25/l de capacité du réservoir, dans une écloserie-laboratoire reliée à un système de recyclage de l'eau de mer synthétique; les post-larves de crevettes ont été amenées jusqu'aux stades juvéniles dans des réservoirs assez peuplés; le taux de survie a été satisfaisant; on prévoit des rendements de l'ordre de 1 000 à 2 000 kg/ha d'étang quand on les aura peuplés de juvéniles de ⩾0·25 g environ. Les principaux problèmes rencontrés lors des essais ont été provoqués par la nature agressive de *M. rosenbergii*, la prédation des larves par un hydrosoaire, *Moerisia lyonsi*, qui s'est installé dans l'écloserie, et des maladies bactériennes. Les priorités fixées pour la recherche future comprennent: la conception de systèmes d'écloseries efficaces, la manipulation génétique destinée à améliorer les caractéristiques de croissance des crevettes et augmenter leur tolérance aux basses températures, la mise au point de rations présentant un bon rapport coût-efficacité, et l'identification ou le développement de marchés appropriés.

La acuicultura experimental del camarón malasio, *Macrobrachium rosenbergii*, en Carolina del Sur, EE UU
Extracto
El texto presenta el desarrollo y primeros ensayos de un sistema modelo para el cultivo de *Macrobrachium rosenbergii* en Carolina del Sur. El modelo comprende cuatro fases fundamentales: (*i*) cria bajo techo de reproductores para la producción de larvas (mediados de octubre a mayo); (*ii*) producción de formas postlarvales utilizando un sistema de incubación con recirculación de agua de mar obtenida sintéticamente (mediados de enero a mayo); (*iii*) utilización de tanques de cria en sistema cerrado para criar las formas postlarvales hasta su paso a juveniles que se siembran en estanques (mediados de febrero a mayo); y (*iv*) cultivo intensivo en estanque de las formas juveniles hasta que alcanzan tamaño comercializable (finales de abril/mayo a mediados de octubre).

Los ensayos preliminares han demostrado la viabilidad técnica del modelo. Se ha mantenido a los camarones reproductores durante el invierno en tanques en sistema cerrado; en la producción de formas postlarvales en una incubadora de laboratorio conectada a un sistema de recirculación de agua de mar sintética se ha obtenido un promedio de 25 unidades por litro de capacidad del tanque; se han criado las formas postlarvales en tanques hasta la fase juvenil a densidades relativamente altas (hasta 500/m^2), con buen indice de supervivencia; y se proyecta obtener rendimientos del orden de 1 000–2 000 kg/ha de estanque sembrando formas juveniles de ⩾0·25 g. Entre los problemas principales que se han encontrado en el ensayo del modelo figuran la naturaleza combativa de *M. rosenbergii*; la depredación de las larvas por un hidrozoo (*Moerisia lyonsi*) que se establece en el sistema de incubación; y las enfermedades bacterianas. Las prioridades para la investigación futura son: preparación de sistemas eficaces de cria, manipulación genética para mejorar las caracteristicas de crecimiento del camarón y aumentar su tolerancia a las temperaturas bajas, obtención de raciones eficaces bajo el aspecto costo, y localización o fomento de mercados adecuados.

1 Introduction

The Malaysian prawn, *Macrobrachium rosenbergii*, has proved to be an excellent organism for warm water aquaculture (Ling, 1962, 1969, 1969a; Fujimura, 1966, 1974; Fujimura and Okamoto, 1970; Shang, 1972; Provenzano, 1973), and interest in its cultivation has become widespread. Following a year of preliminary laboratory studies with native species, the Marine Resources Research Institute of the South Carolina Wildlife and Marine Resources Department began, in mid-1973, to examine the possibility of farming *M. rosenbergii* in South Carolina. For this feasibility study it was necessary to develop a model of *Macrobrachium* aquaculture suitable for this region; prepare a plan of research to develop, test and modify the model and to identify and evaluate alternative models; and assemble an interdisciplinary research team to conduct the broad spectrum of needed research and pilot-scale studies.

In this paper the development and preliminary testing of a *Macrobrachium* aquaculture model for South Carolina are discussed. The research and development plan has been described elsewhere (Sandifer, 1975), and the interdisciplinary research team presently consists of biologists, engineers, economists, nutritionists, a biochemist and an algologist. Various aspects of the research programme are conducted at Clemson University, the Medical University of South Carolina, the University of South Carolina, and the Southeast Utilization Research Center of the National Marine Fisheries Service, with the main effort being at the Marine Resources Research Institute.

2 Model for *M. rosenbergii* aquaculture in South Carolina

2.1 *Background*

Forster and Wickins (1972) described three basic types of aquaculture: (*i*) 'extensive (low stocking densities) or free range culture in very large outdoor ponds or enclosed sea areas'; (*ii*) 'intensive (high stocking densities) outdoor culture in smaller, more controllable ponds, tanks or raceways'; and (*iii*) 'very intensive (high stocking densities with frequent cropping) indoor culture in completely controlled environment tank systems'. The first type was considered for the thousands of acres of former rice fields in coastal South Carolina. However, after careful consideration of the problems of managing and harvesting such impoundments, it appeared that a combination of the two intensive approaches offered greater likelihood of success.

The climate of South Carolina permits outdoor cultivation of *M. rosenbergii* from spring to autumn each year, a period of about 5 to 6 months. Even with this relatively short growing season, intensive culture of prawns in outdoor ponds appears to offer a more immediate potential for profit than does very intensive tank culture, since tank culture technology is not yet well developed.

Full utilization of the available outdoor growing season can be achieved only if post-larval prawns are produced during late winter and early spring. This requires an indoor, controlled-temperature hatchery. A recirculating system employing synthetic seawater was chosen for the hatchery over other types of systems. This selection was based on several factors. First, water temperatures required for rearing *M. rosenbergii* larvae are relatively high (28–30°C) and a recirculating system might substantially reduce heating costs. Second, use of a recirculating system could reduce or eliminate the need for a continuous supply of high quality water, thereby increasing the number of potential hatchery sites. Third, hatcheries utilizing synthetic seawater in a recirculating system could be located on comparatively inexpensive interior lands adjacent to the freshwater grow-out facilities. Thus, a coastal site would be unnecessary, and the numerous advantages of having hatchery and pond facilities at the same location could be realized.

Intensive production of marketable prawns in tank systems is not yet commercially feasible, but recent studies indicate that such systems may have immediate potential for rearing post-larvae to larger sizes for stocking in ponds (Mock, Neal and Salser, 1973; Mock, Ross and Salser, 1975; Sandifer and Smith, 1975). Closed tank systems also

appear satisfactory for holding broodstock indoors over winter.

2.2 *Description of the model*

The model of *M. rosenbergii* aquaculture developed for South Carolina consists of four basic components: (*i*) indoor maintenance of brood stock for production of larvae (mid-October to May); (*ii*) production of post-larvae using a recirculating synthetic seawater hatchery system (mid-January to May); (*iii*) operation of closed system nursery tanks to rear post-larvae to larger juveniles for stocking in ponds (mid-February to May); and (*iv*) intensive pond cultivation of juveniles to marketable size (late April/May to mid-October). This model may also be suitable for other areas with similar climates.

3 Operation of model and preliminary results

3.1 *Maintenance of broodstock in the laboratory*

Adult prawns are held in 40 to 5 000 l laboratory tanks. Each tank is equipped with a separate gravel filter or connected to a large laboratory recirculating system similar to that used for larval culture (see section 3.2.1). Salinity and temperature usually range from 2 to 4‰ and from 25 to 29°C, respectively, in broodstock tanks. Prawns are frequently housed in isolation in small tanks, while in the larger ones mixed populations of males and females are maintained. The isolation method is useful for selective breeding studies and observations on mating behaviour, but the larger 'communal breeding tanks' are more efficient for holding large numbers of adult animals and producing ovigerous females.

No major difficulties have been encountered in holding broodstock for several months in laboratory recirculating sytems, although mortalities due to agonistic behaviour of the prawns are common. In addition, the viability of larvae produced by a given female frequently decreases after repeated spawning in the laboratory. This loss of viability may be related to deficiencies in the material diet (adults are fed only a prepared ration in the laboratory) or perhaps to some physiological factors associated with repeated ovarian development and spawning.

3.2 *Recirculating synthetic seawater hatchery system*

3.2.1 *Description and operating procedures.* The hatchery consists of six 380 l larval culture cones (cylindrical fibreglass tanks with conical bottoms) connected to a 3 700 l capacity water reservoir containing a gravel biological filter. Synthetic sea water, prepared by dissolving Instant Ocean brand sea salts (Aquarium Systems, Inc., Eastlake, Ohio, USA) in warm tap water, is continually recirculated through the tanks and filter. Salinity and temperature are maintained at 12–13‰ and 28–30°C, respectively. A more detailed description of this hatchery system has been provided by Smith, Sandifer and Trimble (1976a).

Ovigerous females with ripe eggs are regularly removed from the various broodstock tanks and transferred into a 400 l communal hatching tank in the hatchery room. Water in the hatching tank is held at 7–8‰ salinity and 28–30°C and continuously recirculated through a built-in gravel filter. Up to 20 females can be accommodated simultaneously in this tank until their eggs hatch. Newly hatched larvae are transferred to the larval rearing cones where they are provided with nauplii of *Artemia salina* at an initial concentration of approximately 5–10/ml of water. The larvae are provided similar amounts of *Artemia* twice daily for the first 20 days of rearing, after which the concentration is gradually decreased. Beginning about the seventh day, the diet is supplemented with grey mullet (*Mugil* spp.) eggs, which are fed at least 4 times daily for the remainder of the larval period. These fish eggs have proved more satisfactory than other diet supplements, such as sieved fish flesh and prepared flake products, tested in our laboratory. Little water is exchanged between the tank and reservoir-filter during the first day of larval culture, but, beginning on the second and continuing until the 25th day, the water recirculation rate is increased by about two tank volumes/tank/day. After day 25 the turnover rate is held at approximately fifty tank volumes/tank/day for the remainder of the culture period.

3.2.2 *Production of post-larvae.* When the hatchery is operated as outlined above some post-larvae are generally observed by days 20–24 and nearly all the larvae metamorphose by days 35–40. Thus far, initial stocking densities have ranged from 67–249 larvae/l of tank capacity and production of post-larvae from 6·6–40·6/l (2 515–15 412/tank). Production averaged 32 post-larvae/l in early rearing trials involving single tanks (Smith, Sandifer and Trimble, 1976a) and 25/l for two production runs in which all tanks were stocked and operated concurrently. These production levels are appreciably higher than those achieved in most other laboratory and hatchery systems (Ling, 1969a; Fujimura and Okamoto, 1970; Wickins, 1972; Fujimura, 1974; Singholka, 1975; Kolke and Potaros, 1975). Yet, mean survival has been relatively low, 31·9% in rearing trials involving single tanks (Smith, Sandifer and Trimble, 1976) and 17·2% for production trials. More than 150 000 post-larvae have been reared in our laboratory-scale hatchery to date using the recirculating synthetic seawater system, and present production capacity for the system appears to be about 60 000 post-larvae in 40 days.

A major problem encountered in operating the hatchery system has been associated with occasional blooms of inadvertently introduced jellyfishes, *Moerisia lyonsi*, which cause high mortalities among the prawn larvae (Sandifer, Smith and Calder, 1974). The small hydrozoan feeds on *Artemia* nauplii and can successfully reproduce within the recirculating seawater system where it may establish high population levels within a few weeks. Medusae also ingest prawn larvae on occasion, but more often the larvae are immobilized by nematocysts and sink to the bottom of the tank where they eventually die. A 1–1·5 hour dip treatment with 250 ppm formalin will kill the medusae but not necessarily the hydroid stage. Short-term eradication has been effected by treating the entire seawater system with formalin or chlorine, but reinfection has usually followed within about 8–12 weeks after treatment. The hydrozoan produces a highly resistant cyst stage which may be responsible for reinfestation of the system. Further research on methods to control outbreaks and to prevent reinfection is under way.

3.3 *Rearing juveniles for later stocking in ponds*

The aggressive and cannibalistic nature of *M. rosenbergii* under crowded conditions has been the major problem encountered in attempts to rear post-larvae in tanks at high

population densities. Addition of various materials to increase surface and shelter area in tanks reduces the problem (Smith and Sandifer, 1975) but does not eliminate it. In densely populated tanks, even with added shelters, many of the juvenile prawns suffer injuries to their appendages and exoskeletons and subsequently develop 'black spot' disease (Goodwin and Hanson, 1976) or are cannibalized.

Survival rates exceeding 90% have been obtained in the Marine Resources Research Institute Laboratory after 6 weeks for post-larvae stocked at 100–200/m^2 of tank floor in 1·8 m diameter tanks without added shelters (Sandifer and Smith, 1975). Similar survival has been obtained at densities of about 500 prawns/m^2 of tank floor in tanks with artificial substrates added (Smith and Sandifer, 1975) and at 400/m^2 in small (2·4 × 1·2 × 0·6 m deep) closed raceways based on the design of Mock, Neal and Salser (1973) (Sandifer and Smith, 1975). In contrast, stocking post-larvae at much higher population densities has resulted in poor survival and growth. For example, only 18% of 54 000 post-larval *M. rosenbergii* stocked into laboratory tanks at 2 700–6 900/m^2 of tank floor during February 1975 survived after 10 weeks of rearing, despite attempts to lower mortality rates by adding shelter units and later reducing the densities.

Disease may also be a serious problem in intensive culture systems. No outbreaks of disease were observed among juveniles until the very intensive rearing attempt of February 1975, when bacterial infections became widespread on the gills, pleopods and uropods of the animals. Of four species of bacteria observed on the prawns, the most prevalent was a filamentous, *Leucothrix*-like organism (D. V. Lightner and J. A. Plumb, personal communications). A morphologically similar bacterium has been reported associated with high mortalities of penaeid shrimp in intensive culture tanks (Lightner, Fontaine and Hanks, 1975). Although the disease infected most of the juvenile *M. rosenbergii* in our tanks, it was not determined whether it contributed directly to the high mortality rates observed. Several treatments were tested in attempts to control the disease. Oxytetracycline (Terramycin) at concentrations of 5, 10, 15, 20 and 30 ppm was used in 1 hour dip treatments with inconsistent results. Furpyrinol (Furanace) at 1 ppm for 1 hour was ineffective. Potassium permanganate at concentrations of 2, 5 and 10 ppm for 1 hour and 1 ppm for 30 hours was effective but caused high mortalities among the prawns (average 9 day post-treatment mortalities were 75·0, 62·5, 75·0 and 81·2% for the 1, 2, 5 and 10 ppm treatments, respectively, compared to 43·7% for the untreated control. Best results were obtained by reducing the population densities and more careful cleaning of tanks.

3.4 *Pond cultivation studies*

In South Carolina, pond grow-out studies with *M. rosenbergii* are being conducted in three small freshwater ponds (0·02–0·04 ha) at the Styx Fish Hatchery in West Columbia, several larger (0·25 ha) freshwater ponds at the Dennis Wildlife Center in Bonneau and one small (0·07 ha) brackishwater pond at the Bears Bluff Laboratory of the US Environmental Protection Agency. These three locations represent the midland, near coastal and coastal regions of the state, respectively. The Styx and Bonneau ponds have sloped bottoms that can be completely drained and are equipped with concrete harvesting basins in the deep ends. The brackishwater pond at Bears Bluff can be completely drained, and there is a small sump near the drain where the animals should collect as the water level is lowered. At the onset of cool weather, the ponds are drained and the prawns removed from the harvest basins with a small seine. The drain-harvest technique appears practical for single crop areas such as South Carolina where the restricted growing season prohibits periodic selective harvesting and partial restocking (Fujimura, 1974).

Preliminary pond rearing trials were initiated in the Styx and Bonneau ponds during spring and summer of 1974 and the most encouraging results were obtained from two of the Styx ponds. In one, juveniles 0·04 g in initial mean weight reached an average size of 10·2 g in 4 months with 59·3% survival, yielding the equivalent of 764 kg/ha. In another pond, larger juveniles (2·7 g in initial mean weight) grew to a mean size of 30·2 g in 5 months with 68·3% survival and yielded the equivalent of about 1 660 kg/ha.

A second series of pond studies was begun in spring of 1975. In early May the Styx ponds were stocked with juvenile prawns 0·24 g in mean weight at densities approximating 6, 10 and 17/m^2 of surface area. During June, three Bonneau ponds were stocked at 3 to 8 prawns/m^2 with newly metamorphosed postlarvae (0·006–0·007 g in mean weight), and the brackishwater pond at Bears Bluff was stocked with 0·07 g prawns at a density of about 7/m^2. Gross production ranged from an equivalent of 572 to 1 499 kg/ha (mean 904 kg/ha) surface area during the 131- to 160 day grow-out studies, and feed conversions of 2·62 to 4·92 (mean 3·59) were obtained (Smith, Sandifer and Trimble, 1976).

4 Discussion

4.1 *Hatchery production*

Recirculating water management systems permit year-round production of post-larvae independent of natural seawater supplies. Additional research is needed to increase hatchery efficiency and production levels and to establish the economic viability of such hatchery systems. In South Carolina there is also an urgent need to develop a pilot-scale hatchery capable of providing sufficient post-larvae for pond rearing experiments and for supply to interested entrepreneurs throughout the state. This hatchery could also provide detailed cost data needed for economic analyses.

4.2 *Pond production*

From preliminary grow-out data available for South Carolina, it appears that yields in the order of 1 000–2 000 kg/ha can be produced in one growing season (5–6 months) if large juveniles (≥0·25 g) are stocked. Yields are projected to decrease substantially as prawn size at stocking decreases. Thus, an efficient, high density prawn nursery system is needed to rear post-larvae to larger juveniles for stocking in grow-out ponds. Improvements in prawn feeds and pond design and management should also result in greater production of marketable prawns.

4.3 *Genetic manipulation*

Currently, the possibility of increasing growth rates and temperature tolerance of *M. rosenbergii* through genetic selection is being evaluated. Data collected in this laboratory suggest that the wide variations in growth rates reported by several investigators (Forster and Wickins,

1972; Wickins, 1972; Fujimura, 1974; Segal and Roe, 1975; Sandifer and Smith, 1975) may be an expression of genetic as well as environmental factors. If so, selective breeding may improve the growth characteristics of *M. rosenbergii* for intensive culture and produce prawns capable of growing at lower water temperatures. The possibility of hybridizing *M. rosenbergii* with native species (*M. acanthurus* and *M. ohione*) is also being examined. Such hybrids might combine desirable characteristics of both parental species (*eg*, the rapid growth and large adult size of *M. rosenbergii* and the greater tolerance to low temperature of the native species). Further, hybrid organisms frequently exhibit heterosis, or hybrid vigour, in which desirable culture characteristics of the hybrid surpass those of both parent stocks.

4.4 *Prawn nutrition*

Although some private pond culture operations, notably those in Hawaii, are approaching commercial success using presently available feeds, more nutritious, cost-effective rations are needed. Such feeds might enhance yields from pond culture and are necessary for highly intensive culture in controlled systems where natural foods are not available to supplement the prepared rations. Current and planned research concerning major dietary requirements of the prawn ultimately should lead to production of improved prawn rations.

4.5 *Engineering and design studies*

Engineering studies presently under way on tank design, water circulation and waste treatment should improve aquaculture technology and accelerate the development of commercial prawn culture. Significant advances have already been made in determining the operating characteristics of airlift pumps for aquacultural applications (Castro, Zielinski and Sandifer, 1975) and evaluation and design of larval culture systems (Zielinski, Castro and Sandifer, 1974). Efforts are now directed toward developing intensive nursery systems for juveniles.

4.6 *Marketing*

The feasibility of commercial prawn culture in South Carolina and elsewhere will ultimately be determined by economics. Therefore, development of suitable markets is crucial. Establishment of *M. rosenbergii* as a gourmet food, perhaps priced between shrimp and palinurid lobsters in local markets, should improve the chances for successful commercial culture here. However, if the cultured prawns must be marketed through the established local channels for heads-off shrimp, then the economic outlook is expected to be much less favourable. Studies to identify and develop local and export markets for the prawns are needed.

5 Conclusions

The model of *M. rosenbergii* aquaculture proposed here, namely intensive indoor rearing of larvae and juveniles during the cooler months followed by intensive pond culture during the warmer months, appears practical for South Carolina and other similar temperate zone areas. Nevertheless, much additional research is needed in the areas of culture technology, pond management, prawn genetics, and nutrition if prawn farming is to become a commercial reality in such areas.

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Desarrollo Larval de *Macrobrachium tenellum* en El Salvador

C. Sánchez

Extracto

Entre el mes de mayo y septiembre de 1974 se realizaron ensayos en la Estación Piscícola de Santa Cruz Porrillo, El Salvador, con el objeto de conocer el desarrollo de larvas del camarón de río *Macrobrachium tenellum* en acuarios, utilizando los métodos para cultivar especies de camarones del mismo género. Se efectuaron experimentos únicamente en acuarios con agua salobre (salinidad 16 por mil) con capacidad de 80 l y sistemas de filtración y recirculación.

Se usaron hembras colectadas en los ríos y mantenidas junto a los machos en estanques de arcilla. Cuando éstas se encontraban sexualmente maduras se pasaban a los acuarios de observación. Sólo unas 5 000 larvas lograron sobrevivir hasta 30 días y de éstas sólo 10 vivieron 52 días, pasando por varias fases en su desarrollo. No se observó la transformación de dichas larvas en juveniles. La alimentación consistió básicamente en nauplii de *Artemia*.

A pesar de que la técnica mejoró con respecto a los resultados de años anteriores, la calidad del agua y la alimentación siguen siendo factores fundamentales necesarios a ser perfeccionados para poder emprender los experimentos de producción en mayor escala.

Larval development of *Macrobrachium tenellum* in El Salvador

Abstract

From May to September 1974, trials were made at the Santa Cruz Porrillo Fish Farming Station, El Salvador, to study the development of the river prawn, *Macrobrachium tenellum*, larvae in aquaria, employing methods used for cultivation of other species of the same genus. Experiments were conducted in brackish water (salinity 16 ppt) in 80 l aquaria with filtering and recirculation systems.

The females used were collected from rivers and kept with the males in earthen tanks. When the females reached sexual maturity they were transferred to observation aquaria. Only about 5 000 larvae survived as long as 30 days, and of these only 10 lived 52 days, going through different stages of development. No transformation of the larvae into juveniles was observed. The basic diet consisted of *Artemia* nauplii.

Although the methods were improved compared to those used in previous years, the quality of the water and the diet remain fundamental factors that must be perfected to enable production experiments on a larger scale.

Développement larvaire de *Macrobrachium tenellum en El Salvador*

Résumé

Entre mai et septembre 1974, la Station piscicole de Santa Cruz Porrillo, El Salvador, a pratiqué des essais pour étudier le développement des larves de la crevette fluviatile *Macrobrachium tenellum* en aquarium, en utilisant les méthodes appliquées pour élever des espèces de crevettes du même genre. Les expériences ont été faites uniquement en aquariums d'eau saumâtre (salinité de 16 pour mille) d'une capacité de 80 l et pourvus de systèmes de filtration et de recirculation.

Des femelles capturées dans des cours d'eau ont été placées avec des mâles dans des bassins d'argile. Une fois parvenues à maturité sexuelle, elles étaient transférées dans les aquariums d'observation. Quelque 5 000 larves à peine ont survécu 30 jours et 10 d'entre elles seulement ont atteint l'âge de 52 jours, passant par diverses phases de développement. La transformation de ces larves en juvéniles n'a pu être observée. Leur alimentation était essentiellement à base de nauplii d'*Artemia*.

Bien que la technique ait été perfectionnée par rapport aux années précédentes, la qualité de l'eau et l'alimentation demeurent des facteurs fondamentaux qu'il importe d'améliorer pour pouvoir entreprendre des assais de production à plus grande échelle.

1 Introducción

El cultivo del camarón de río del género *Macrobrachium* ha preocupado durante los últimos años a muchos investigadores y biólogos de distintos países. La importancia de desarrollar este tipo de cultivo se debe a la alta calidad de su carne para la alimentación humana y al elevado precio que ésta alcanza en casi todos los mercados mundiales. A todo esto en nuestro caso se suma también el interés en el conocimiento de la biología de estas especies y su preservación como recursos naturales. Sin embargo muchos han comprobado que su cultivo no es sencillo, sobre todo en cuanto al desarrollo larval y a los costos de producción se refiere y salvo en muy raros casos estos últimos siguen siendo muy altos.

La primera especie cultivada con éxito fue el *M. rosenbergii* (Fujimura, 1966; Ling, 1967). Estos autores hicieron los primeros estudios sobre la biología de dicha especie y desarrollaron las técnicas necesarias para su cultivo en gran escala. Más tarde Fujimura y Okamoto (1972) efectuaron en Hawai el cultivo masivo de dicha especie, pero tuvieron problemas con el crecimiento de los juveniles y con la determinación de la alimentación más adecuada.

Costello (1971) logró cultivar en Florida (EE.UU.) con éxito *M. acanthurus*, *M. carcinus* y *M. ohione*. Dugan y Frakes (1972) hicieron un estudio sobre el desarrollo larval a diferentes salinidades y encontraron que 16 partes por mil era apropiado para mantener baja la tasa de mortalidad.

Rasalan, Delmendo y Reyes (1967) hicieron estudios sobre el desarrollo de *M. lanceifrons* en Filipinas con el objeto de aplicar las técnicas a una especie mayor en el futuro.

En El Salvador existen cuatro especies de la familia Palaemonidae, todas del género *Macrobrachium*, pero de éstas sólo dos, *M. americanum* y *M. tenellum* poseen valor comercial (Holthuis, 1954).

Las primeras investigaciones en el cultivo de *Macrobrachium* se hicieron en 1972 y 1973 (Sánchez, 1972 y 1973) en la Estación Piscícola de Santa Cruz Porrillo, donde se trabajó con *M. tenellum*, *M. americanum* y *M. digueti*, descartando posteriormente este último por su pequeño tamaño.

En principio los resultados no fueron muy alentadores por falta de equipo y demás estructuras necesarias para realizar el trabajo, pero a partir de 1974 la Estación se vió implementada con nuevos laboratorios y el equipo necesario para este tipo de investigación. Aunque, por el momento, nos limitamos a trabajar a nivel de laboratorio, la experiencia obtenida en estos primeros ensayos será orientada en el futuro hacia un cultivo masivo.

La especie seleccionada para este estudio fue el *M. tenellum* por ser la más abundante, por poseer tenazas débiles incapaces de lesionar al que los manipula y por aparente incapacidad de desplazarse fuera del agua por sus

pereiópodos débiles en comparación con el peso de su cuerpo.

2 Materiales y métodos

2.1 *Captura de reproductores*

En el mes de marzo de 1974 se trajo a la estación 100 juveniles de *M. tenellum* procedentes del Río San Antonio, Departamento de La Libertad. Estos fueron capturados con red de playa (chinchorro) en la desembocadura de un pequeño estero formado por el río, cerca del puente sobre la carretera del litoral.

2.2 *Transporte y adaptación*

Los juveniles capturados fueron trasladados en bolsas de polietileno con agua oxigenada. Una vez traídos a la estación fueron colocados en un estanque de concreto de 20 m^2 con 50 cm de agua. Se hicieron refugios colocando transversalmente unas tiras cortadas de placas de asbesto cemento acanalado.

El tamaño promedio fue de 5 cm desde la punta del rostro hasta el punto medio en el borde posterior del telson y con un peso promedio de 2 g.

2.3 *Alimentación*

Se les suministró alimento en forma de píldoras (Porrillo II) y pescado picado fresco crudo alternándolas cada día, a razón de un 5% del peso total corporal diario. Sesenta días después los camarones medían como promedio 9,1 cm y pesaban 9,7 g.

2.4 *Obtención de hembras ovígeras*

Durante el mes de agosto los camarones de río se encontraban sexualmente maduros. Al trasladar las hembras maduras algunas desovaron en los estanques, muchas otras lo hicieron en los acuarios del laboratorio.

2.5 *Medición de parámetros*

Las lecturas de salinidad se hicieron con un medidor de conductividad (HACH, Modelo 2511) y el pH se determinó con un potenciómetro (Photovolt, Modelo 126A) y con un equipo Helligue para pH. El oxígeno disuelto y temperatura se determinaron con un medidor de oxígeno (YSI) electrónico.

2.6 *Técnicas de incubación*

Los acuarios utilizados eran todos de vidrio, con 76 l de capacidad y dimensiones diferentes según el caso.

Los filtros utilizados en todos los acuarios eran Dynaflo, Modelo 425, externos y en una ocasión se usó la combinación con un filtro biológico Halvin, Modelo 279-A. Se emplearon además lámparas de luz ultravioleta (Hydroster I) para esterilizar y termostatos para regular la temperatura del agua.

La temperatura del agua se mantuvo en todos los casos entre 28 y 29°C, el pH entre 8,1 y 8,4, la salinidad alrededor de 16 por mil salvo en el caso donde se usó agua dulce como prueba.

Las hembras se extrajeron del estanque y se seleccionaron las que poseían huevos adheridos a los pleópodos y otras que estaban más próximas al desove por el grado de desarrollo del embrión (Sánchez, 1972). Estas se colocaban en acuarios con salinidad del agua de 12 partes por mil incrementando lentamente la salinidad a 16 partes por mil (Bardach, Ryther y McLarney, 1972). A las hembras, se les alimentaba, durante este período, con alimento especial en barras de alta proteína aglutinada con alginatos de elevada resistencia a la dilución en agua (Meyers, Butler y Hastings, 1972). Dicho alimento era ávidamente ingerido por las hembras. El agua marina usada se trajo en recipientes hechos de fibra de vidrio de una playa arenosa cercana. Este agua se mantuvo tapada una semana y se filtraba antes de usarse a través de un filtro para las diatomeas.

Se probaron las siguientes técnicas de incubación:

(*i*) En dos acuarios 64 × 39 × 30 cm con salinidad de 16 partes por mil preparada con una mezcla de agua marina natural y agua de pozo sin cloro. Se usó un filtro externo con lana de vidrio y carbón activado. Antes de caer al acuario, el agua pasaba bajo una lámpara de luz ultravioleta, como fondo se usó arena gruesa de concha molida lavada y bajo ésta había un filtro biológico para la filtración del agua a través de la arena, con el objeto de eliminar el amoníaco transformándolo así en nitrito. Además se utilizó una piedra aireadora.

(*ii*) En dos acuarios similares a los anteriormente descritos se colocaron hembras con idénticas condiciones pero el agua salobre (16 partes por mil) se fabricó artificialmente usando sales para acuarios marinos ('Instant Ocean' de Aquarium Sytems Inc.) para eliminar la posibilidad de tener el agua marina en malas condiciones.

(*iii*) Se preparó un acuario de 76 × 31 × 30 cm con agua totalmente dulce, con filtro externo y lámpara ultravioleta pero sin arena y sin filtro interno.

(*iv*) En un acuario de 100 × 28 × 25 cm se colocaron 3 filtros externos: (*a*) con carbón animal, (*b*) con arena de concha molida y (*c*) con lana de vidrio pero sin arena y sin filtro interno. A uno de los filtros pasaba el agua a través de una lámpara de luz ultravioleta como en el caso anterior y se agregó dos piedras aireadoras para mantener el oxígeno y la agitación del agua al máximo. La salinidad se mantuvo desde un principio en 16 partes por mil con agua de mar natural y todos los parámetros físico-químicos en la forma antes mencionada.

(*v*) Se repitió este tipo de ensayo pero sin la lámpara ultravioleta.

2.7 *Alimentación de larvas*

Las larvas nacidas fueron alimentadas desde el primer día, con nauplii de *Artemia*, a razón de una cucharadita diaria dividida en dos porciones (mañana y tarde). Además se trató de complementar esta dieta durante los dos primeros días, con algas liofilizadas, preparadas para camarones *Penaeus*, pero no se observó que las larvas tomaran este alimento.

Se probó también alimentar las larvas con zooplancton y alimentos preparados (Tetra Brine Shrimp, molido) pasados en forma seca por un tamiz ('Saran'). Este alimento era aceptado por las larvas con edad de ocho días pero no se utilizó más tarde durante el experimento porque ensuciaba el fondo y descomponía el agua debido a que no era completamente aprovechado por las larvas. Los alimentos eran suministrados mediante un gotero (Fujimura, 1966; Ling, 1967).

2.8 *Limpieza de los acuarios*

Diariamente se limpiaban los filtros y los fondos de los acuarios a través de un sifón, pero éste siempre succionó

muchas larvas que después murieron allí. Una vez cada diez días se limpiaba totalmente el acuario pasando la totalidad de las larvas a otro acuario situado en un nivel más bajo a través de un sifón de 6 mm de diámetro interior (de Tygón). Una vez lavado el acuario se devolvían las larvas cuidadosamente al acuario anterior que contenía la misma agua. Cada 5 días se renovaba un 25% del agua en cada acuario y diariamente se hacían los ajustes necesarios de salinidad y temperatura. En estas labores de limpieza, se producían siempre considerables mortalidades de las larvas en todos los sifones. Este inconveniente se redujo algo aumentando el número de sifones en cada filtro de modo que la presión del agua sobre la tela protectora fuera menor.

3 Resultados y discusión

Los resultados obtenidos en el curso de este experimento se pueden resumir en la siguiente forma.

Con la técnica (*i*) las larvas no sobrevivieron más de 4 días y no se observó desarrollo alguno durante este tiempo. Aparentemente la altura del acuario fue un factor crítico para la supervivencia de las larvas. Esta no debe sobrepasar los 29 cm como lo demostraron los experimentos con la técnica (*iv*) donde el desarrollo fue normal con un nivel de agua de 27 cm como altura máxima. Otro factor negativo en esta técnica fue la posición del filtro (bajo la arena). Aunque este tipo de filtro biológico resulta excelente para peces, en el caso de las larvas de camarón dificulta mucho la limpieza del fondo. Los residuos se descomponen alterando la calidad del agua rápidamente, sobre todo si la acción de las bacterias nitrificantes no es suficientemente enérgica para contrarrestar este cambio.

El resultado de la técnica (*ii*) fue igual al anterior. Esto nos demuestra que la calidad del agua de mar usada en la técnica (*i*) no fue un factor determinante y por consiguiente quedó descartada la necesidad de usar agua marina sintética de tan alto costo.

En la técnica (*iii*) donde el agua era totalmente dulce, las larvas vivieron entre 4 y 5 días solamente a pesar de haber eliminado otros factores problemáticos como el filtro de arena y la excesiva altura del nivel de agua. Esta corta supervivencia de las larvas nos demuestra que la salinidad cercana a 16 partes por mil es el factor limitante en el desarrollo y la supervivencia de las larvas de *M. tenellum*.

La técnica (*iv*) produjo los mejores resultados. Las dos hembras mantenidas en las condiciones de este sistema desovaron simultáneamente. Los desoves resultaron en un 100 por ciento de supervivencia de las larvas. Se calculó que en el acuario eclosionaron unas 20 000 larvas y aunque sabíamos que esta población era muy elevada para sobrevivir en un espacio tan reducido, nos interesaba principalmente conocer si el método empleado era efectivo con el transcurso del tiempo y cuál sería el porcentaje de sobrevivientes en el caso de que las condiciones fueran buenas.

El alimento constaba únicamente de recién eclosionados nauplii de *Artemia* a razón de una cucharadita de huevos por día. Esta dósis se mantuvo, con muy poca variación, durante todo el proceso. La técnica de alimentación se basó en la fototaxis tanto de las artemias como de las larvas de camarón, las que normalmente se reunieron en un pequeño sector del acuario. Las artemias se introducían en el acuario por un gotero y mientras se efectuaba la operación de alimentación, todos los filtros se paraban para mantener el agua tranquila y facilitar a las larvas la captura de las artemias. Una hora después, cuando todas las larvas habían comido, se reanudaba la actividad de los filtros.

Al nacer las larvas medían 2 mm. Diez días después su tamaño fue 2,8 mm, muriendo un 50% de ellas. Siete días más tarde 10 000 larvas vivían en buenas condiciones y medían entre 3,2 y 3,3 mm. A los treinta días había unas 3 000 larvas las cuales medían como promedio 4 mm. A partir de esta fecha la tasa de mortalidad incrementó sensibilemente reduciéndose notablemente su número de día en día. A los 45 días sobrevivieron unas 50 larvas las cuales medían entre 5 y 6 mm de longitud promedio. Solamente diez larvas sobrevivieron 52 días.

Durante este lapso de tiempo las larvas pasaron por unos 7 a 8 estadios larvales y en la última etapa larvaria eran muy semejantes a los juveniles, aunque nunca adquirieron hábitos bénticos, como corresponde a la fase juvenil del camarón.

Los resultados inadecuados obtenidos con la técnica (*v*) (sin lámpara ultravioleta) pueden atribuirse más bien al pobre desove de las hembras que a la falta de acción bactericida de la luz ultravioleta, pues sólo el 10% de las larvas eclosionaron y éstas sobrevivieron sólo 6 días.

4 Conclusiones

De todas las técnicas probadas en el curso del experimento la que mejores resultados dió fue la técnica (*iv*) sección 2.6. De estos resultados se deduce que las condiciones logradas por filtración y alimentación se aproximan a las condiciones ambientales para el desarrollo larval de *M. tenellum*.

Las conclusiones se pueden resumir en la siguiente forma:

(*a*) Bajo la salinidad del agua cercana a unas 16 partes por mil se obtuvo aceptables rangos de incubación y supervivencia larval.

(*b*) La alimentación, consistente básicamente en nauplii de *Artemia*, es altamente eficiente sobre todo durante los primeros 30 días de su vida.

(*c*) El oxígeno, pH, temperatura y demás parámetros físico-químicos han sido mantenidos dentro de los límites de tolerancia de las larvas.

(*d*) La profundidad del agua es un factor crítico en la supervivencia de las larvas y ésta no debe exceder los 30 cm de altura.

(*e*) El éxito de trabajo en el desarrollo larval depende básicamente en el cuidadoso manejo de las hembras maduras. De este manejo dependerá buena incubación y desove más o menos completo con la consiguiente elevada tasa de supervivencia de las larvas.

(*f*) Sin haber logrado la transformación de larvas hasta el estadio juvenil, deducimos que el desarrollo larval de *M. tenellum* es más largo y con más estadios que el de *M. rosenbergii*.

5 Recomendaciones

Según las experiencias antes descritas se deduce que es factible el desarrollo artificial de larvas de *M. tenellum*. Aunque, actualmente, no se ha logrado completar su ciclo biológico en laboratorio, estamos seguros que en el curso de las futuras investigaciones se lograrán estos objetivos. Es recomendable por lo tanto seguir trabajando sobre las bases ya establecidas y descritas en este trabajo pero también

efectuar cambios que se pueden resumir en la siguiente forma:

(*i*) Sustituir *Artemia* por otros tipos de alimentos de menor costo.

(*ii*) Estudiar otros sistemas de filtración de agua más eficientes que ocasionen menos daños a las larvas.

(*iii*) Encontrar la forma de cómo aislar eficientemente las larvas durante la limpieza del acuario, para que éstas no sean succionadas por los sifones de limpieza.

(*iv*) Trabajar con menor número de larvas por unidad de volumen para mejorar la tasa de superviviencia.

(*v*) Estudiar técnicas semejantes a las empleadas para *M. tenellum* también para la especie *M. americanum* con alto valor comercial.

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Various Aspects of Culturing the American Lobster, *Homarus americanus*

J. E. Stewart and J. D. Castell

Abstract

A large and generally profitable fishery for the lobster, *Homarus americanus*, has existed in eastern North America for many years. The increasing scarcity and consequent high prices of lobsters have generated interest in rearing them commercially. Key problems in lobster culture are protection against diseases, nutritional requirements, acceleration of growth, coping with aggressive behaviour and low cost physical facilities designed to require a minimum of labour for operation.

The disease gaffkemia, caused by the bacterium *Aerococcus viridans* (var.) *homari*, is the most serious infection which affects the lobster, periodically causing severe mortalities. Very few cells of a virulent strain of the pathogen are required to initiate an infection and normal lobsters possess no resistance to gaffkemia. Transmission takes place when wounds or breaks in the integument occur in the presence of the pathogen. The cause of death is attributed to the early wasting nature of the disease which results in a massively impaired hepatopancreas. The disease course is completely temperature dependent. Some success in treatment has been achieved with antibiotics, notably vancomycin, if administered early in the course of the disease. Induction of resistance as a prophylactic measure shows promise.

Protein requirements in feeds fall within the 40–60% range of the dry weight of the diet. Cholesterol is required and there appears to be a requirement for the linolenic family fatty acids. Work with juvenile lobsters indicates that minerals and vitamins D and E are required, but vitamins A and K are probably not essential. Growth enhancement in juvenile lobsters was achieved by combining a good diet with eyestalk ablation at 20°C. The increases in weight were a result of increased tissue synthesis and not merely increased water retention.

A new larval rearing system, which has potential for commercial application, was designed and used successfully.

Différents aspects de l'élevage du homard Américain (*Homarus americanus*)

Résumé

Une pêcherie importante et généralement rentable exploite le homard *Homarus americanus* à l'est de l'Amérique du nord depuis de nombreuses années. Du fait de la pénurie croissante de homards et des prix élevés qui en résultent, on s'intéresse à l'élevage commercial de ce crustacé. Les principaux problèmes que pose l'élevage du homard sont: la protection contre les maladies, les besoins nutritionnels, l'accélération de la croissance, la lutte contre l'agressivité du comportement, et la création d'installations peu coûteuses nécessitant un minimum de main-d'oeuvre.

La 'gaffkemia', maladie causée par la bactérie *Aerococcus viridans* (var.) *homari* est la plus grave des infections qui attaquent les homards et provoque périodiquement de lourdes pertes. Il suffit de quelques cellules d'une souche virulente de l'agent pathogène pour déclencher l'infection et normalement les homards n'offrent aucune résistance à la 'gaffkemia'. Il y a transmission de la maladie lorsque l'agent pathogène se trouve en présence de blessures ou de déchirure du tégument. La mort est attribuée au dépérissement rapide occasionné par la maladie qui entraîne une dysfonction poussée de l'hépathopancréas. L'évolution de la maladie est étroitement liée à la température. Quelques succès dans le traitement de cette maladie ont été obtenus par l'emploi d'antibiotiques, particulièrement la vancomycine, à condition qu'ils aient été utilisés au début de l'infection. L'induction de la résistance en tant que mesure prophylactique a donné des résultats encourageants.

La demande de protéines se situe à un taux d'environ 40 à 60% de matière sèche dans la nourriture. Le cholestérol est nécessaire ainsi que les acides gras linoléniques. Les recherches sur les homards au stade juvénile ont prouvé que des minéraux et des vitamines D et E sont nécessaires, mais que les vitamines A et K ne sont probablement pas essentielles. On a stimulé la croissance chez les juvéniles en combinant un bon régime alimentaire avec l'ablation du pédoncule de l'œil à 20°C. L'augmentation de poids résulte de l'augmentation de la synthèse tissulaire et non simplement de la rétention d'eau.

Un nouveau système d'élevage des larves susceptible d'être appliqué industriellement a été élaboré et exploité avec succès.

Aspectos del cultivo del bogavante Americano *Homarus americanus*

Extracto

En la costa septentrional de América del Norte existe desde hace muchos años una importante pesquería de bogavante *Homarus americanus*, en general rentable. La creciente escasez del bogavante, con el consiguiente aumento de los precios, ha hecho surgir el interés por la cría comercial de este bogavante. Los problemas claves para el cultivo del bogavante son la protección contra las enfermedades, las necesidades nutricionales, la aceleración del crecimiento, el comportamiento agresivo de estos crustáceos y la preparación de instalaciones de poco costo que exijan para su funcionamiento una mano de obra mínima.

La enfermedad gaffkemia, causada por la bacteria *Aerococcus viridans* (var.) *Homari*, es la infección más grave de las que afectan al bogavante, causando periódicamente graves mortalidades. Bastan poquísimas células de una cepa virulenta de este agente patógeno para dar comienzo a una infección de gaffkemia, contra la que el bogavante normal no tiene ninguna resistencia. La infección tiene lugar cuando se producen heridas o roturas del integumento en presencia del agente patógeno. La causa de la muerte se atribuye a los rápidos efectos devastadores consuntivos de la enfermedad, que resultan en una lesión aguda del hepatopáncreas. El curso de la enfermedad depende totalmente de la temperatura. Se han logrado algunos éxitos con el tratamiento con antibióticos, sobre todo vancomicina, en las primeras fases de la enfermedad. La resistencia inducida parece ser una medida profiláctica prometedora.

Las necesidades de proteínas en los piensos oscilan entre el 40 y el 60% del peso en seco de la ración alimenticia. Es necesario

suministrarles colesterol, y también parecen ser necesarios ácidos grasos linolénicos. Los trabajos realizados con formas juveniles han indicado que son necesarios minerales y vitaminas D y E, mientras probablemente las vitaminas A y K no son esenciales. Se ha conseguido acelerar el crecimiento de las formas juveniles de bogavante combinando una buena ración alimenticia con la ablación de los pedúnculos oculares a 20°C. El aumento de peso se debe a un aumento de la síntesis tisular y no meramente a una mayor retención de agua.

Se ha diseñado y utilizado con éxito un nuevo sistema de cría de larvas, que ofrece buenas posibilidades de aplicación comercial.

1 Introduction

For many years the lobster, *Homarus americanus*, has been the basis of a large and generally profitable fishery on the Atlantic coast of Canada and the northeastern United States. Despite the economic benefits of the fishery and the fact that the lobster industry is based on the sale of live animals which are held in captivity for up to several months at a time, many aspects important to the fishery and the animals' well-being have not been studied in depth. Increasing scarcity of the lobster and its extremely high price have stimulated concern over the management of the lobster fisheries and generated interest in rearing lobsters under controlled conditions.

Two subjects essential to successful aquatic culture operations, which often do not receive the attention they deserve, are disease and nutrition. Many of the disease problems which plague a culture operation are the result of opportunistic infections allowed to develop through poor husbandry. There is no substitute for good management in preventing diseases of this kind. There are, however, diseases over and above these that are highly specific and can cause epizootics which virtually eliminate specific groups of animals within a very short period. Unfortunately, the genus *Homarus* is susceptible to a specific disease of this kind, namely gaffkemia, caused by the bacterium *Aerococcus viridans* (var.) *homari* (formerly named *Gaffkya homari*). High mortalities among captive lobsters have been recorded in periodic epizootics of gaffkemia.

Each animal has its unique nutritional needs which must be met adequately if maximum production and survival are to be achieved. The nutritional requirement of the lobster is a subject which has been virtually untouched. Information on this subject is required not only as part of the data desirable for proper management of the lobster fishery but also for culture operations. Unless the interaction of the lobster with the components of its ecological niche is fully understood, it is difficult to determine whether its needs (including nutritional requirements) are being satisfied and, thus, difficult to make valid decisions on management of wild or cultured stocks. This is particularly true in circumstances where environmental conditions normally fluctuate because of natural events or man-made causes. In culture operations, food is usually the most expensive item; consequently, it is imperative that the diet used produces a high-quality product in the shortest possible time at the least cost.

The slow growth rate of the lobster in nature is a major factor impeding its culture in North America. In the wild it takes 5–7 years for this species to reach market size of approximately 450 g (Wilder, 1953). Hughes, Sullivan and Shleser (1972) were able to shorten this to two years by rearing lobsters at 22°C. The cost of fuel is rising, however, and it may not be economically sound to heat sea water to increase lobster growth rate unless large sources of waste heat are used. It has long been known that bilateral eyestalk ablation results in accelerated moulting and growth rates in decapod crustaceans (Passano, 1960) and it is, therefore, possible that a combination of elevated temperatures, adequate diets and eyestalk ablation will go far toward making lobster culture commercially feasible.

A final area of concern that has been largely overlooked is that of well designed holding facilities. Though relatively large numbers of lobsters are held in captivity in tidal pounds for up to 6 months, losses due to cannibalism and disease are sometimes greater than 50% (Wilder, 1953). Lobster culture will require special units for rearing from eggs to marketable sizes. Several different systems for each stage or size of development may be required and will obviously require direct collaboration between biologists and engineers.

Ultimately the question becomes, can all of these facets be combined to produce a market sized lobster at a profit? It is important, therefore, that an accurate and realistic evaluation be made of all costs related to lobster culture. This paper discusses some important aspects of lobster culture in general and describes detailed results of investigation of disease, nutrition and growth enhancement of lobsters undertaken at the Halifax Laboratory, Nova Scotia, Canada.

2 Disease aspects

The lobster disease, gaffkemia, has plagued the live lobster trade in the United States, Canada and Europe, probably since its inception. The disease was first recognized as a specific bacterial infection by Snieszko and Taylor (1947). They isolated the causative agent from lobsters in Maine, showing it to be the bacterium which Hitchner and Snieszko (1947) named *Gaffkya homari*, and which more recently was changed to *Aerococcus viridans* (var.) *homari* (see Kelly and Evans, 1974; Stewart and Arie, 1974). This bacterium is a gram positive, catalase negative, beta-haemolytic, tetrad-forming coccus which appears to possess no exoenzymes (Snieszko and Taylor, 1947; Hitchner and Snieszko, 1947; Hucker, 1957; Stewart, Foley and Ackman, 1969). This lack of exoenzymes and consequent lack of invasive powers results in the bacterium being transmitted only through breaks or ruptures in the integument of the host which permit entry to the haemolymph. The exposure to *A. viridans* (var.) *homari* must come simultaneously with or soon after integumental rupture for the pathogen to circumvent the lobster's rapid and effective wound-sealing mechanism. Transmission does not occur when the lobster ingests infected material since the acidity of its gastric fluid (pH 5·0) is lethal to *A. viridans* (var.) *homari*. Despite the pathogen's lack of invasive powers, the development of epizootics is aided by the aggressive behaviour of lobsters, which provides wounds for entry, and by the fact that normal lobsters have no apparent resistance to the pathogen after entry. Small numbers (10 or less per kg of lobster weight) of a virulent strain of *A. viridans* (var.) *homari*, injected into the haemolymph are sufficient to ensure a fatal infection. Injection, however, of large numbers (6×10^8/kg) does not accelerate the infection sufficiently to produce a significant decrease in time from infection to death.

The huge numbers of pathogens present in weakened or dead animals (1×10^9/ml of haemolymph) are released to the water during cannibalism and are available for infecting other lobsters in the immediate vicinity. Thus, one infected

animal introduced to a unit is sufficient for the initiation of an epidemic resulting in the death of most of the other animals (Stewart and Rabin, 1970). Sufficient numbers of lobsters have been examined bacteriologically externally to discount completely the suggestion that the bacterial pathogen, *A. viridans* (var.) *homari*, is a part of the normal microflora of the lobster's external surfaces. There are no external signs of the disease with the exception that, as the infection proceeds, the lobsters become lethargic and progressively weaker until they die.

As the disease develops, the lobster suffers a massive decrease of circulating haemocytes, resulting in impairment of the clotting mechanism by removal of the clot-initiating factor contained in the haemocytes. The fibrinogen levels and other haemolymph proteins are not affected significantly. As a result of the loss of haemolymph clotting power, the risk of a fatal haemorrhage is introduced in the event of wounding.

Variations in temperature and salinity have been shown to have a marked effect on the disease. Since development of gaffkemia infections in lobsters is strictly temperature dependent, the disease remains largely dormant during the cold water months. At 1°C the pathogen *in vivo* does not increase in numbers and the infection is subpatent until the temperature is increased. Then it flourishes and kills the host in a time span directly dependent upon the ambient temperature. The temperature influence on means for times to death are 172 days at 3°C, 84 at 5°C, 65 at 7°C, 28 at 10°C, 12 at 15°C, and 2 at 20°C. In addition, the pathogen easily survives periods at 1°C, *in vivo* or *in vitro*, which are more than sufficient to carry the bacterium from one warm water season to the next.

Biochemically the death of lobsters infected with *A. viridans* (var.) *homari* is believed to be the result of an unsuccessful competition on the part of the lobsters for their own readily available energy reserves (Stewart *et al.* 1969). The development of the pathogen *in vivo* takes place at the expense of haemolymph glucose and amino acids. Since the lobster will not feed after the second day of the infection at 15°C it is unable to replenish those nutrients used by the pathogen except at the expense of its own tissue, mainly the glycogen reserves (Stewart *et al.* 1972). Thus, the general decline in glycogen in the skeletal muscle, the heart, and hepatopancreas is paralleled by a reduction of adenosine triphosphate, especially in the hepatopancreas where it is virtually eliminated (Stewart and Arie, 1973). The resulting massive inpairment of the hepatopancreas, the major organ for biosynthesis and detoxification, is considered the direct cause of death.

It was stated earlier that normal lobsters invariably succumb to infections with a virulent strain of the pathogen, thus exhibiting no natural resistance to gaffkemia. It has been possible, however, to combat the infection by reducing holding temperatures by early (but not late) intervention with the antibiotic vancomycin (Stewart and Arie, 1974), and by induction of a form of resistance through injection of vaccines (Stewart and Zwicker, 1974). Work on induction of resistance with vaccines is in its early stages and although not perfected shows promise of being effective.

The various aspects of the disease described suggest a number of guidelines for avoiding many of the problems stemming from this and other diseases (described previously by Stewart, 1974): (*i*) Transfer of animals from one operation to another should be avoided as much as possible. (*ii*) Animals intended for introduction to a culture operation should be examined for the presence of disease prior to shipment, and upon arrival should be held in suitable isolated quarantine facilities for a definite time period and proved to be free of specific diseases and parasites. (*iii*) Dead animals or those showing any signs of disease should be removed from general operating areas immediately and the cause of death or infection determined. (*iv*) Carcasses of animals removed because of death or disease must be sterilized before being used for food for the remaining animals. (*v*) Animal units should be kept small and stocked at as low a density as may be consistent with production techniques. (*vi*) A single or common water supply should not be used in closed or recycling systems. (*vii*) Crossovers between units of animals, nets, *etc*, should be kept to the absolute minimum. (*viii*) Methods and means for sterilizing individual units must be readily available. (*ix*) Temporary environmental changes (in this example, lower water temperature) can be used to afford a certain measure of protection or reduce the intensity of the epizootic to assist the culturist in coping with the emergency.

3 Nutritional requirements

Virtually nothing was known until recently of the nutritional requirements of lobsters. Consequently, initial experiments at the Halifax Laboratory have been concerned with the most obvious nutrient factors, such as protein and lipid level requirements. Work by Brockerhoff, Hoyle and Hwang (1970), showing that the gastric fluid of lobsters had more protease activity than any other enzyme, prompted a protein level requirement study (Castell and Budson, 1974). The studies of Kanazawa *et al* (1970, 1971, 1971a); Shudo *et al* (1971), Teshima and Kanazawa (1971), and Zandee (1967) on the sterol requirements of related species led to further work with cholesterol (Castell, Mason and Covey, 1975). This investigation was followed by an evaluation of the effects of the level and type of dietary lipid required (Castell and Covey, in preparation).

The initial experiments on dietary protein and lipid were conducted with adult (300–600 g) lobsters with which it is possible to monitor serum chemistry as well as carry out a detailed analysis of the effects of diets on size and composition of vital organs. The much faster growth rate and early onset of nutritional deficiency signs in juvenile lobsters, however, led to increased use of juvenile lobsters (0·2–5 g) for most studies. In all experiments the animals were held in separate compartments to prevent cannibalism and were supplied with continuously flowing, 20°C, filtered sea water (physical conditions have been described previously in Castell and Budson, 1974).

The optimum protein dietary level for adult lobsters (fed 0, 20, 40 or 60% casein) was in the 40–60% range. This conclusion was based on routine observation of condition indices including frequency of moulting, chemical serum analyses, weight change, percentage of edible meat in animals at termination, and composition of several vital organs and tissues.

In experiments with juveniles, it was shown that there was a requirement for cholesterol in lobster diets. This finding is in agreement with the results obtained by Kanazawa *et al* (1970, 1971, 1971a) in their determinations of the dietary sterol requirements of the kuruma prawn, *Penaeus japonicus*. The actual concentration of cholesterol

required by juvenile lobsters appears to be approximately 0·5% of the diet.

The protein and cholesterol data were then used in formulating diets for another study using adult lobsters to determine dietary lipid requirements (Castell and Covey, unpublished data). It was found that cod liver oil (CLO) resulted in significantly greater weight gains than either corn oil (CO) or hydrogenated coconut oil (HCO) when each of these were fed as 10% of the dry weight of the diet. The CLO diet also resulted in a higher yield of edible meat, higher serum protein values, greater numbers of haemocytes in the haemolymph and better feed conversion (weight feed/weight gain) than either CO or HCO. The optimal dietary level of CLO was found to be 5% of the dry weight of the diet. Removal of all sterols from CLO prior to its inclusion in the diet resulted in reduced weight gains, higher feed conversion, and lowered serum protein. All of these deficiency symptoms were prevented by the addition of 1% cholesterol to the sterol-free CLO diet.

It is postulated that the superior nutritional value of CLO is related to an essential fatty acid (EFA) requirement by lobsters for $\omega 3$[1] type of linolenic family fatty acids. The CO is high in $\omega 6$ or linoleic acid and very low in $\omega 3$ fatty acids. Though the results with adults are less dramatic than those with juveniles, the data suggest that mature lobsters also have a dietary requirement for a sterol such as cholesterol.

Further work with juvenile lobsters (unpublished) has shown that a dietary supplement of mineral salts is essential for good growth and shell formation, and that for shell pigmentation β-carotene will not serve as a substitute for natural pigments such as astaxanthine.

Preliminary work with fat soluble vitamins has shown that vitamins D and E are essential and that A and K may not be required. Vitamin D deficiency, in addition to slow growth and low survival, also results in soft and deformed shells. Work in the near future will include the analysis of the qualitative and quantitative requirements of juvenile lobsters for fat soluble vitamins and essential amino acid requirements.

4 Growth enhancement

The long time required for lobsters to reach market size in their natural environment is one of the major constraints to development of a lobster culture industry. Several investigations have been undertaken on techniques to reduce this long growth period and various alternatives and combinations of these show some promise. Hughes, Sullivan and Shleser (1972) reduced the normal growth period of 5–7 years to about 2 years by rearing lobsters at approximately 22°C. The use of heated sea water will only be practical, however, when the heat source is inexpensive. Thus, it may be possible to establish a lobster culture industry in conjunction with the heated effluent from thermal power plants.

Another technique which may be effective in reducing the growth period is bilateral eyestalk ablation. It was shown as early as 1905 (Zeleny, 1905) that removal of both eyestalks from some crustaceans resulted in precocious moulting and accelerated growth. The subject of moult control and the related involvement of eyestalks in crustaceans has been reviewed by Passano (1960). The initial reports on attempts to accelerate the growth rates of lobsters by eyestalk ablation were, however, not very encouraging. Flint (1972) reported that removal of both eyestalks from American lobsters seemed to lengthen rather than shorten the moult cycle. Additionally, although Sochasky, Aiken and McLeese (1973) using immature female and small mature male lobsters, and Rao, Fingerman and Fingerman (1973) working with juveniles, were able to accelerate the moulting rates by eyestalk ablation, the survival of ablated animals after moulting was very poor in both cases.

The poor survival of ablated lobsters may be related to diet and nutrition as suggested by Smith (1940) for ablated crayfish. Flint (1972) fed his lobsters liver chunks. Rao, Fingerman and Fingerman (1973) fed their juveniles guppy food. The authors have had good success with ablated juvenile lobsters fed either frozen brine shrimp (*Artemia salina*) or diets containing natural ingredients, such as crab, squid, mussels, clams, or oysters.

In the first experiment, 20 juveniles in the seventh or eighth stage were ablated and 13 unoperated controls were held and fed under identical conditions (Mauviot and Castell, in preparation). Regression curves for weight plotted against time were determined for both the eyestalk-ablated and control lobsters, based on growth data for 200 days after the operation. The correlation coefficients for these curves were 0·975 for the ablated and 0·889 for the control lobsters. At 200 days the calculated average weight was 49·8 g for ablated lobsters and 10·6 g for the control animals. The regression analysis curves predict that one year after ablation the blinded lobsters would average about 1 600 g compared with about 150 g for the control animals.

The increased growth rate of the eyestalk-ablated lobsters was the result of both a shortened moult cycle and an increased weight gain after moulting. The average time between the first and second moult of ablated lobsters was $13·5 \pm 1·4$ (standard error) days compared with $22·7 \pm 3·4$ for the controls. The average percentage weight gain for the ablated lobsters was $93·1 \pm 15·4$ versus $71·0 \pm 9·8$ for the controls.

The accelerated growth as measured by weight gains was, in fact, a result of increased tissue synthesis, since there was no significant difference between ablated and control lobsters in the percentage moisture or protein in the muscle, or the percentage moisture in the whole animal. The faster growth rate of the ablated lobsters, however, did result in a lower deposition of lipid, especially in the hepatopancreas.

Although much research is still needed on this technique the positive results so far are very encouraging. It does seem possible that eyestalk ablation and increased temperatures could be used to accelerate growth in commercial lobster culture using either juveniles or intermediate sized lobsters captured in the wild and reared to market size in captivity.

5 Culture systems

Lobster culture will require several distinctly different systems for different stages in the lobster's development. One system which is used extensively in lobster culture operations is the larval pot developed in the Massachusetts State Hatchery on Martha's Vineyard, Massachusetts (Hughes, Shleser and Tchobanoglous, 1974). With the

[1] Refers to the position of the first double bond counting from the methyl end of a fatty acid.

Hughes' larval pots, it is possible to rear 50–80% of the very large number of larvae produced from an average female to the fourth or fifth or juvenile stages. The greatest number of survivors reared in the Hughes' pots were obtained when larvae were fed live adult brine shrimp (*Artemia salina*).

A simpler system has been devised at the Halifax Laboratory for rearing larvae immediately after hatching with equivalent survival rates. Larvae are held in a static system, consisting of rectangular, fibreglass aquaria equipped with air stones and supplied with 50–100 l of sea water. The water is changed every 2 or 3 days. The larvae are supplied with an excess of newly-hatched brine shrimp nauplii. As long as an excess of these nauplii is available, cannibalism is almost nil. The rectangular tanks are much simpler and more readily available than Hughes' pots. Less labour is required since a single daily feeding is adequate. The brine shrimp remain alive and are available in the tank until eaten. When the eggs of each female hatch, larvae are placed in separate tanks and thus it is easier to keep different age groups and families separate. Thus, larval rearing is not an obstacle, and the real problems in developing culture systems arise in providing adequate facilities for the culture of lobsters beyond the larval stage.

In the nutrition work at the Halifax Laboratory, juveniles are reared in individual compartments to prevent cannibalism. There are, however, a number of aspects of the juvenile rearing system that might have some application to a commercial culture system. The bottoms of the tanks slope downward to the centre of the tank where a bottom drain permits continual removal of waste food and faecal material thereby reducing the labour required to keep the tanks clean (Fig. 1). An external drain pipe with flushing siphon assists in the removal of waste products. An overflow drain on the side of the tank would permit floating debris to be removed. A plastic, or plastic-coated, wire-mesh false bottom prevents the lobsters from being flushed down the drain. Such a system could be enlarged for commercial-scale production.

The physical facilities for mass or commercial rearing of larger-sized lobsters must make provision for:

(*i*) Reduction of cannibalism. This may be achieved through physical separation of the animals by providing individual compartments with burrowing cover, such as scallop shells or drainage tiles. It may also be possible to find means to reduce the aggressive behaviour of lobsters kept in close quarters.

(*ii*) Minimum labour. The designs for physical facilities should incorporate as much automatic cleaning and feeding as possible and facilitate easy observation and monitoring of stocks.

(*iii*) Inexpensive and easily controlled heat source. One of the more attractive sources is obviously waste heat from thermal power stations or similar units if the drawbacks inherent with this heat loss can be overcome. Another is the recycling of heated water. The second alternative entails initial capital costs but lower operating costs, and requires the development of effective high capacity filters, especially biological filters.

(*iv*) Protection against introduction and spread of disease. Quarantine facilities must be available. Connexions in water services between major units should not be permitted, or kept to an absolute minimum to reduce the hazards of spreading diseases throughout the entire operation in the event of their accidental introduction.

Research on commercial lobster culture systems is being conducted at several centres in North America. Interesting work on physical facilities for culture is being carried out at the San Diego State University, San Diego, California, at the Bodega Bay Laboratory of the University of California, Davis, California and at St. Andrews Biological Station, Fisheries and Marine Service of Canada, St. Andrews, New Brunswick. In addition, an interesting concept for a potential commercial polyculture system which includes rearing of lobsters has been proposed by the staff at Woods Hole, Massachusetts.

The real test of all the research on lobster culture will be in actual pilot-scale operations with careful cost evaluation. The high market value and increasing scarcity of lobsters in nature, combined with all the research efforts in the area, suggest that lobster culture may be feasible in the near future.

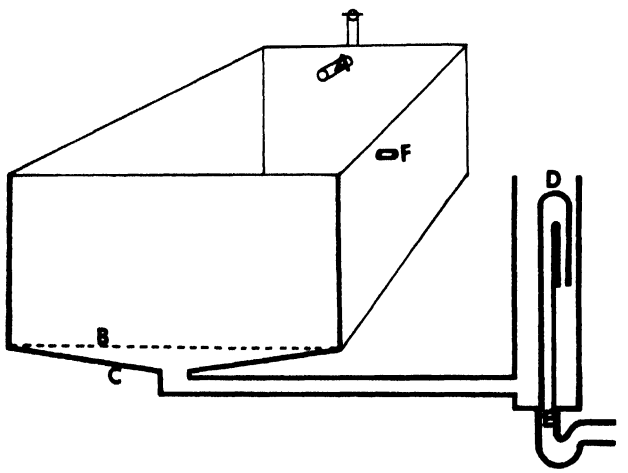


Fig. 1. Rearing system for juvenile lobsters (A—seawater supply; B—mesh bottom; C—sloping bottom to facilitate waste removal; D—external stand pipe with siphon which gives continuous flushing action; E—standpipe is removable so aquarium can be completely drained; F—overflow drain to permit removal of floating waste).

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Rearing Larvae and Post-Larvae of the King Crab (*Paralithodes camtschatica*)

T. Nakanishi

Abstract

Experiments on culturing the larvae and post-larvae of king crab (*Paralithodes camtschatica*) have been conducted in Hokkaido, Japan since 1970.

Egg-bearing female king crab were held in chambers where the larvae hatched. The larvae were reared in chambers (1·8 × 0·9 × 1·0 m) holding 1·6 tons of water. Half of the water was renewed daily. It was kept well aerated and held under 10°C. The zoeae were fed nauplii of *Artemia salina*. During their fourth stage, the zoeae were reared in Saran net cages (0·9 × 0·9 × 0·4 m) set in running water. Their diet of *Artemia* nauplii was augmented by shrimp juice, clam and *Laminaria*. The rate of survival of zoeae raised at a density of 400 000/chamber was over 80%.

Post-larvae were held on two types of bottom: sand and in the same Saran net cages used for fourth stage zoeae. The net cage was much more satisfactory in that good water quality (*ie*, free from residual food and other particles) was maintained. Initial survival of the glaucothöe starting with 1 000–50 000 was good, but mortality increased suddenly and, at the first stage of the young crab, the final number of glaucothöe was only 210–500. Cannibalism and unsuitable foods were believed to be the most important factors limiting survival. (The best food was that given to the fourth zoeal stage.)

The first stage young crab were cultured up to their fifth stage using the same methods as for the glaucothoe stage. From the sixth stage on, they were held in a rearing chamber (1·8 × 0·9 × 0·7 m) with a sand bottom. The food was similar to that of the glaucothoe stage. Water temperature was held at 10°C in 1971. From 1973 on, without control of temperature, it rose to 20°C but survival was unchanged from that in 1971.

It was concluded that mass culture of king crab zoeae was not difficult but success in rearing post larvae was not attained.

Elevage de larves et de post-larves de crabe royal (*Paralithodes camtschatica*)

Résumé

Depuis 1970, on procède à des expériences d'élevage de larves et de post-larves de crabe royal (*Paralithodes camtschatica*) à Hokkaido (Japon).

On a placé des femelles fécondées de crabe royal dans des bacs où s'est produite l'éclosion des larves. Les larves ont été élevées dans ces bacs (1,8 × 0,9 × 1,0 m), qui contenaient 1,6 tonnes d'eau, renouvelée pour moitié chaque jour, bien aérée, et tenue à une température de 10°C. Les zoés ont été nourries à l'aide de nauplies d'*Artemia salina*. Pendant leur quatrième stade, les zoés ont été élevées dans des cages en filet du type Saran (0,9 × 0,9 × 0,4 m) disposées dans une eau courante. Le régime alimentaire constitué de nauplies d'*Artemia* a été complété par l'adjonction de jus de crevettes, de clam et de *Laminaria*. Le taux du survie des zoés élevées à une densité de 400 000 par réservoir a excédé 80%.

Les post-larves ont été conservées sur deux types de fond: sable et filet des cages du type Saran utilisées pour les zoés du quatrième stade. La cage en filet a donné des résultats bien plus satisfaisants en préservant la qualité de l'eau (qui était en effet exempte de résidus alimentaires et d'autres particules). Le taux de survie initial des glaucothoes a tout d'abord atteint un chiffre satisfaisant (1 000–50 000), mais la mortalité a augmenté rapidement et, au premier stade du jeune crabe, le nombre final des glaucothoes n'était que de 210–500. On pense que le cannibalisme et l'utilisation d'aliments inadéquats ont été les facteurs limitatifs de la survie les plus importants (le meilleur régime alimentaire a été celui administré au quatrième stade zoé).

Le jeune crabe a été élevé du premier au cinquième stade par les mêmes méthodes que celles ayant servie au stade glaucothoe. A partir du sixième stade, les crabes ont été placés dans des bacs d'élevage (1,8 × 0,9 × 0,7 m) sur fond de sable. L'alimentation était analogue à celle administrée au stade glaucothoe. L'eau était maintenue à une température de 10°C en 1971. A partir de 1973, en l'absence de contrôle, la température s'est élevée à 20°C, mais le taux de survie n'a pas varié par rapport au chiffre atteint en 1971.

Le document conclut que l'élevage de masse du crabe royal au stade zoé n'est pas difficile, mais que l'élevage des post-larves n'a pas été couronné de succès.

Cría de formas larvales y postlarvales de centolla (*Paralithodes camtschatica*)

Extracto

Desde 1970 se han realizado en Hokkaido, Japón, experimentos de cultivo de formas larvales y postlarvales de centolla (*Paralithodes camtschatica*).

Se colocaron hembras ovadas en cámaras, hasta la salida de las larvas. Las larvas se criaron en cámaras (1,8 × 0,9 × 1,0 m) con 1,6 toneladas de agua, renovando diariamente la mitad del agua. Las camaras se mantuvieron bien aireadas y a menos de 10°C. Se alimento a las zoeae con nauplii de *Artemia salina*. Durante su cuarta fase, las zœae se criaron en jaulas de red Saran (0.9 × 0.9 × 0.4 m) colocadas en agua en movimiento. Se completo la racion alimenticia con nauplii de *Artemia* con jugo de camaron, almejas y *Laminaria*. El indice de supervivencia de las zoeae criadas en densidades de 400 000/camara fue superior al 80%.

Para las postlarvas se utilizaron dos tipos de fondos: de arena y las mismas jaulas de red Saran utilizadas para la cuarta fase zoea. La jaula de red resultó mucho más satisfactoria, ya que permitió mantener una buena calidad del agua (es decir, exenta de residuos de alimentos y otras particulas). La supervivencia inicial de las glaucothöe, comenzando con 1 000–50 000, resultó buena, pero la mortalidad aumentó de repente y en la primera fase de centolla el número final de glaucothöe fue sólo de 210–500: se cree que los factores más importantes que limitaron la supervivencia fueron el canibalismo y la inadecuación de los alimentos. (El mejor alimento resultó ser el suministrado a la cuarta fase zoea.)

Las centollas se cultivaron desde la primera hasta la quinta fase utilizando los mismos métodos que en la fase de glaucothöe. A partir de la sexta fase se colocaron en cámaras de cría (1,8 × 0,9 × 0,7 m) con fondo de arena, utilizando alimentos análogos a los de la fase de glaucothöe. La temperatura del agua se mantuvo a 10°C en 1971. A partir de 1970, sin control de temperatura, ésta aumentó a 20°C, pero la supervivencia permaneció invariada respecto a la de 1971.

Se llegó a la conclusión de que el cultivo en masa de zoeae de centolla no es difícil, aunque la cría de formas postlarvales no se logró.

1 Introduction

The king crab (*Paralithodes*) fishery of the North Pacific is one of its high value fisheries. The world catch for king crab in 1966 was 149·6 thousand tons; by 1973 it had declined to 59·8 thousand tons. Meanwhile, the Japanese catch had declined from 31·0 tons in 1966 to 6·2 tons in 1973 (FAO, 1974). Such a decline, coupled with increased demand for this much desired crustacean, has made attempts to cultivate it artificially important.

There are many studies on rearing larvae of the king crab, *Paralithodes camtschatica*. Kaai (1940) studied the rearing of king crab larvae from the zoeal to the post-larval stage in rearing chambers in the field. He reported that the larvae had four zoeal stages and one glaucothöe stage. Sato and Tanaka (1949) reared the larvae in a laboratory. Kurata (1959 and 1961) reared the larvae from the first zoeal stage to the ninth post-larval stage in a laboratory. His study outlined a method for culturing both larval and post-larval king crab.

Meanwhile, the kuruma prawn (*Penaeus japonicus*) and the Japanese blue swimming crab (*Neptunus pacificus*) are both cultured on a large scale in western Japan. Such large-scale rearings demonstrate the possibility of similar large-scale rearing of king crab larvae.

In 1970, the experiments on crab aquaculture began at the Akkeshi Marine Biological Station of Hokkaido University, Hokkaido Regional Fisheries Research Laboratory, Hokkaido Kushiro Fisheries Experimental Station, Hokkaido Marine Cultivation Center and the Nemuro Fishermen's Co-operative Association in Hokkaido, northern Japan. One of the major projects is large-scale rearing of king crab larvae. Rearing of the larvae, which started in 1970, continues in Nemuro in eastern Hokkaido. The physiology and ecology of king crab larvae and post-larvae are also being studied in a laboratory. A summary of the studies on the king crab follows.

2 Methods and results

2.1 *Eggs and spawning*

Egg-bearing female king crabs were caught in crab pots and taken to the laboratory. They were placed in chambers (2·0 × 1·0 m) where the larvae were hatched. These larvae which are phototactic were gathered by attracting them to a light and put into rearing chambers (1·8 × 0·9 × 1·0 m).

Some egg-bearing females were caught in the autumn and reared until the next spring in the laboratory (in 1973). They were collected near Nemuro (1971–75), near Mombetsu (1973) and in Bristol Bay in the North Pacific (1971 and 1974).

Eggs survived over 240 hours in air of 100% humidity at 3° and −1°C, while adult crabs survived in the air for about 7 hours at 5°C (Nakanishi, 1974). Egg-bearing females could be carried for about 7 hours exposed to air, and were carried for over 7 hours in sea water. Almost all of the egg-bearing females that were carried in air spawned. But when the temperature during transport was above 10°C or under −2°C, their spawning rate was very low. Some egg bearers that were reared over the winter did not spawn.

The greater part of the larvae hatched out in one week. Larvae that hatched out during or just after transport did not survive up to the second stage. Larvae that hatched out three days after the first spawning did not survive.

The rate of oxygen consumption by the eggs was almost constant at oxygen saturations higher than 70% and decreased at oxygen saturations lower than 60%. The rate was almost constant at water temperatures of 3°, 6° and 8°C, and decreased at temperatures higher than 8°C. From these facts, it appears that the eggs maintain themselves best at water temperatures lower than 3°C and at oxygen saturations higher than 70%.

2.2 *Rearing the zoeal stage*

The number of zoeae reared in one rearing chamber ranged from 50 000 to 400 000. Half of the water in the chamber was changed daily and the water was always kept well aerated. Residual food and moulted carapaces were removed once a day.

Artemia salina nauplii were used as food during the zoeal stage. The average number of nauplii consumed by a zoea throughout its entire stage was about 760 (Kurata, 1960). As the zoeal stage occupies a period of about 30 days at 8°C, an average zoea consumes about 25 nauplii per day.

The optimum number of zoeae to be reared in a chamber with a water volume of 1·6 tons appears to be about 30 000–50 000. In the first experiments, it was found that the zoeae gathered at one place in the chamber, where they attacked each other and would not eat much of the proffered foods. Lights were placed at each corner of the rearing chamber and turned on one by one every 7·5 minutes. The zoeae moved phototactically from one lighted spot to the next one. (The nauplii of *Artemia salina* are also phototactic.) By use of this method, all of the space in the rearing chamber was used by the zoeae and they consumed a good deal of food. If, however, the number of zoeae in a rearing chamber was under 50,000, they could be reared in good condition without use of these lights.

Kurata (1960a) and Omi and Mizushima (1972) studied the influence of temperature upon the survival and growth of larval and post-larval king crabs. They showed that the optimum temperature for the larvae was 8°C. The water temperature of the rearing chambers was maintained under 10°C. In 1972 and 1975 the water temperature of some chambers rose above 10°C and a large number of larvae reared at this higher temperature did not develop to the glaucothöe stage.

During the fourth zoeal stage, they were fed shrimp juice, clam, and the brown seaweed *Laminaria* together with *Artemia salina* nauplii. The zoeae were reared in Saran net cages (0·9 × 0·9 × 0·4 m) set in running water. The oxygen consumption rate in these zoeae held at 8°C was almost constant at oxygen saturations higher than 60%. The rate of survival of the zoeae was over 80%. The rate of survival of the zoeae reared at a density of 400 000 per chamber was also over 80%.

It was concluded that mass culture of zoeae was not very difficult.

2.3 *Rearing post-larvae*

Two types of bottom were used for the rearing chambers for post-larval king crab. One was of sand (5–10 mm in diameter); the other was the Saran net cage used for the fourth-stage zoeae. In nature, the post-larvae live on a sand bottom

but this substrate did not appear to be very good for their mass culture in a laboratory. Residual foods, moulted carapaces and other small particles which settled on the sand were so small that they could not be removed completely. The particles decomposed and the water deteriorated in quality. Net-cage rearing did not have these problems. Running water was used and the cages were cleaned once a day.

It was easy to count the post-larvae. The number of glaucothöe reared in one cage was 1 000–50 000 at first, but the mortality increased suddenly at this stage and the final number of glaucothöe at the time of development into the first stage of the young crab was 210–500 in most cases. One reason for this increased mortality was cannibalism. Glaucothöe sometimes swam, but usually they remained on the bottom or held on to the net. Polypropylene films or Saran nets were used to increase their clinging areas. However, many glaucothöe gathered under these films or nets where they held on to each other and attacked each other. This method was not very useful, therefore, in protecting the glaucothöe from cannibalism. Shortage of suitable foods appeared to be another reason for increased mortality. Many kinds of foods were tried out during the glaucothöe stage. The foods provided for the fourth zoeal stage seemed to be the best of those tried, but they were still far from perfect. This stage of the king crab is very different morphologically, ecologically and physiologically from the zoeal stage, and increase in mortality may have been dependent on many factors still unknown at this time. Mass culture methods for the glaucothöe stage have not yet been studied.

The glaucothöe moult and develop into the first stage of the young crab. The young crabs were cultured up to their fifth stage using the same method as for the glaucothöe stage. From their sixth stage on (now with a carapace length of about 3 mm), they were kept in a rearing chamber ($1{\cdot}8 \times 0{\cdot}9 \times 0{\cdot}7$ m) with a sand bottom. The food used during this stage was similar to that given during the glaucothöe stage but was of larger size.

The water temperature in the rearing chamber was held under 10°C in 1971. From 1973, this stage was reared without control of the water temperature. The highest temperature was about 20°C, but the rate of survival was no different from that in 1971 (see Table I).

TABLE I
SURVIVAL RATE OF THE KING CRAB FROM FIRST ZOEAL TO ADULT STAGES IN EXPERIMENTS CONDUCTED 1970–74

Year	*Number of first-stage zoeae*	*Survival rate* (%)					
		Z_2	Z_3	Z_4	G	A_1	A_2
1970	20 000	[a]	[a]	0·4	0·2	0	0
1971	270 000	92	92	90·0	5·7	2·2	1·0
1972	20 000	[a]	92	85·0	0·4	0	0
1973	178 000	[a]	[a]	85·0	34·0	1·1	0·45
1974	1 800 000	[a]	92	90·0	90·0	0·5	0·1

[a] Not counted

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The Brine Shrimp, *Artemia salina*: A Bottleneck in Mariculture?

P. Sorgeloos

Abstract

For many years the freshly hatched nauplii of the brine shrimp (*Artemia salina*) have been the most common live food used in mariculture of finfish and crustacea. The cysts from which *A. salina* nauplii hatch are harvested from unmanaged wild populations by primitive techniques and at only a few places in the world. As a result, good quality cysts are available only in limited quantities. With expansion of mariculture, demand for these cysts is exceeding the supply, which may lead to a serious bottle-neck in many aquaculture developments.

A review of the studies on brine shrimp shows that the present critical situation can only be alleviated by revising the commercial exploitation of the cysts, as well as the practical use made of the latter in mariculture farms. In this respect it is suggested that:

(*i*) The quality of commercially available cysts can be improved and their quantity increased by the application of new harvesting techniques.

(*ii*) As salt lakes with *Artemia* are found all over the world (the collection at the State University of Ghent totals more than 60 different strains), comparative studies on the ecological characteristics and the nutritional value of different geographical races will lead to the selection of those that are best suited for aquacultural purposes.

(*iii*) Hatching of the larvae, followed by their separation from the hatching debris can be optimized by the application of new and standardized techniques. This can lead to increased survival of larvae by at least 50% and a reduction of 90% in the equipment and labour involved.

(*iv*) Biochemical analyses to determine nutrient value of the larvae indicate that freshly hatched *Artemia* nauplii should be offered to the predator as soon as possible after hatching.

(*v*) High density culturing techniques for *Artemia* larvae have been developed that are fully automatic and economically feasible. By using air-water lift operated raceways, densities of 3 000 shrimps per litre can be cultured from the first nauplius to the adult stage within 2 weeks on a diet of commercially available dried algae.

(*vi*) The use of juvenile brine shrimp larvae of appropriate sizes instead of freshly hatched nauplii offers several nutritional and economical advantages in terms of utilization by fish and crustacean predators.

La crevette de marais salant, *Artemia salina*: un problème pour la mariculture

Résumé

Depuis de nombreuses années, on a utilisé le plus souvent, en mariculture pour fournir une nourriture vivante aux poissons et aux crustacés, des nauplii nouvellement éclos de la crevette de marais salant (*Artemia salina*). Les œufs qui sont utilisés pour l'élevage de l'*A. salina* sont récoltés au moyen de techniques rudimentaires dans des populations à l'état sauvage qui ne se trouvent que dans quelques rares endroits du monde. On ne trouve donc d'œufs de bonne qualité qu'en quantités limitées. Etant donné l'extension de la mariculture, la demande d'*Artemia salina* est supérieure aux possibilités d'approvisionnement ce qui risque de faire sérieusement obstacle à son développement.

Lorsque l'on reprend les travaux théoriques et pratiques qui ont été

consacrés à la crevette de marais salant on constate que la situation difficile où l'on se trouve à l'heure actuelle ne pourrait être modifiée que par un changement dans l'exploitation commerciale des œufs ainsi que dans l'utilisation que l'on en fait en mariculture. On propose donc à cet égard les mesures suivantes:

(*i*) La qualité des œufs disponibles dans le commerce pourrait être améliorée et leur quantité accrue par l'application de nouvelles techniques de récolte.

(*ii*) Etant donné que l'on trouve dans le monde entier des lacs salés peuplés d'*Artemia* (les collections de l'Université de l'Etat de Gand en réunissent plus de 60 différentes souches), des études comparatives sur les caractéristiques écologiques et la valeur nutritionnelle des races originaires de différentes régions permettraient de choisir celles qui apparaîtraient les plus propres aux besoins de l'aquaculture.

(*iii*) En utilisant de nouvelles techniques normalisées il serait possible d'améliorer l'éclosion des larves et leur séparation des débris d'éclosion. Ce qui permettrait d'augmenter au moins de 50% la quantité de larves survivantes et de réduire de 90% le matériel et la main-d'œuvre nécessaires.

(*iv*) Les analyses biochimiques effectuées en vue de déterminer la valeur nutritive des larves montrent que les nauplii d'*Artemia* nouvellement éclos doivent être fournis aux prédateurs aussitôt que possible après leur éclosion.

(*v*) Des techniques totalement automatisées, et satisfaisantes du point de vue économique, ont été mises au point pour la culture à haute densité des larves d'*Artemia*. En utilisant des raceways actionnés à l'eau et à l'air, on peut élever jusqu'à 3 000 crevettes par litre, depuis le stade du nauplius jusqu'à l'âge adulte, en les soumettant pendant deux semaines à un régime à base d'algues séchées qui sont en vente dans le commerce.

(*vi*) Il est à bien des égards avantageux des points de vue nutritionnel et économique d'utiliser pour nourrir des poissons et des crustacés prédateurs de jeunes larves de crevettes de marais salants, parvenues à une taille suffisante, plutôt que des nauplii nouvellement éclos.

Problemas que plantea para la maricultura la limitada disponibilidad de camarón de agua salobre, *Artemia salina*

Extracto

Durante muchos años, los nauplii recién eclosionados del camarón de agua salobre (*Artemia salina*) han sido el alimento vivo más comúnmente utilizado en el cultivo de peces y crustáceos marinos. Los quistes de los que salen los nauplii de *A. salina* proceden de poblaciones silvestres, y se recogen, con técnicas primitivas, sólo en pocos lugares del mundo. Debido a ello, las disponibilidades de quistes de buena calidad son limitadas. Al extenderse la maricultura, la demanda empieza a ser superior a la oferta, lo que podría causar un grave inconveniente para muchas actividades acuícolas.

Examinando los estudios fundamentales y aplicados que se han hecho sobre el camarón de agua salobre, es evidente que la actual situación crítica sólo puede aliviarse revisando el sistema de explotación comercial de los quistes y su empleo práctico en maricultura. A este propósito, se sugiere que:

(*i*) Podría aumentarse la calidad y cantidad de quistes disponibles comercialmente aplicando nuevas técnicas de recolección.

(*ii*) Dado que se encuentran en todo el mundo lagos de agua salada con *Artemia* (la colección de la Universidad estatal de Gante comprende más de 60 variedades diferentes), podrían hacerse estudios comparativos de las características ecológicas y el valor nutricional de las diversas razas geográficas para seleccionar las más adecuadas para la acuicultura.

(*iii*) La salida de las larvas del quiste y su separación de los restos de éste, puede perfeccionarse aplicando técnicas nuevas y uniformes. Podría obtenerse así un aumento de la supervivencia de las larvas de al menos el 50%, y una reducción del 90% del equipo y la mano de obra necesarios.

(*iv*) Los análisis bioquímicos hechos para determinar el valor de las larvas desde el punto de vista nutricional indican que los nauplii de *Artemia* deben ponerse a disposición de los depredadores lo antes posible después de eclosionados.

(*v*) Se han preparado técnicas de cultivo de larvas de *Artemia* en grandes densidades, que son plenamente automáticas y económicamente viables. En canales con un sistema de elevación de agua y aireación pueden criarse en dos semanas hasta 3 000 camarones por l, desde la primera fase de nauplius hasta la fase adulta, con una dieta de algas secas que pueden adquirirse comercialmente.

(*vi*) El empleo de juveniles de camarón de tamaño adecuado en vez de nauplii recién eclosionados ofrece varias ventajas nutricionales y económicas por lo que se refiere a su utilización por los peces y crustáceos depredadores.

1 Introduction

Seale (1933) and Rollefsen (1939) described the high value of nauplii of *Artemia salina* as food for fish fry and thus effectively changed the direction of controlled indoor fish culture. Indeed, it was soon found that the cysts of the brine shrimp, which accumulate along the shores of salt lakes, are a practical food source. When kept vacuum-dry, the cysts remain viable for years; they can easily be exported all over the world and, on immersion in sea water, produce nauplii within approximately 24 hours.

During the last decade, the research effort as well as the practical implementation of commercial fish and crustacean farming have increased considerably. As a consequence, the demand for brine shrimp cysts, which are harvested for commercial purposes from only a few salt lakes in North America, has increased markedly and now exceeds the supply. Not only is the price for cysts rising continuously, but the acute dependence of mariculture farms on provision of good quality *Artemia* cysts places a considerable burden on further expansion of maricultural activities.

In view of this situation, a thorough analysis of the *Artemia* problem should be given high priority in order to prevent shortage of brine shrimp cysts becoming a bottleneck in mariculture development.

2 Commercial exploitation of brine shrimp cysts

As controlled production of brine shrimp for the harvesting of cysts has not been accomplished on a commercial basis, the only source of *Artemia* eggs is still from cyst-deposition by unmanaged wild populations that are subject to major environmental perturbations. In fact, production of brine shrimp has been primarily a by-product of salt-production plants. Water management for salt production is often unfavourable for the development of *Artemia* and the high production of brine shrimp and their eggs occurs unpredictably when the environmental conditions are accidentally suited for these halophilic organisms.

The techniques for harvesting the cysts are quite primitive: driven by wind and currents, the floating cysts accumulate along the shores of salt lakes, where they are ladled out into bags. The time lapse, however, between washing ashore till harvesting is not constant and is often spread over several weeks. At each rainfall during this period, cysts can undergo a hydration and dehydration cycle, which results in a temporary activation of cyst metabolism. Fundamental studies related to this subject have shown that the energy content of cysts which have been subjected to repeated hydration-dehydration cycles, decreases and that the size of the nauplii hatching from these cysts is reduced significantly (Sorgeloos, 1975). In the extreme case of multiple exposure to hydration-dehydration cycles, the energy content of the cysts drops below a critical level and subsequent hatching becomes impossible.

Complaints of mariculture operators on the significant differences in hatchability from one batch of cysts to another can be at least partly explained by the repeated activation-inactivation of metabolism during the period the cysts are on shore prior to their harvest. Cyst quality could be optimized and kept constant by either more frequent harvesting or by preventing the cysts from accumulating on the shore. In the latter case, although immersed, the cysts will remain in the dormant stage and will only hatch when the salinity drops below 70 ppt.

Despite the fact that salt lakes with natural populations of brine shrimp are found throughout the world, they are commercially exploited for *Artemia* cysts in only a few places, mainly in North America, *ie*, Great Salt Lake, Utah,

USA; salt pans in the San Francisco Bay area, California, USA; and salt lakes in Saskatchewan, Canada.

In the State University of Ghent laboratory, a collection of over 60 different strains from all continents has been made. A comparative study of these strains has revealed differences in important characteristics, such as the hatching rate, size of nauplii, viability, optimal temperature, and salinity ranges for larval growth and survival, *etc.* (Sorgeloos *et al.* 1975).

Further studies on the determination of the ecological characteristics as well as the nutritional value of these strains should lead to the selection of those best suited for aquacultural purposes. This can lead to transplantation experiments with inoculation of particular strains into biotopes where, for example, the autochthonous *Artemia* races have poor characteristics with respect to their use in mariculture.

The application of both the selection studies and better harvesting techniques can alleviate the present critical demand for *Artemia* cysts. Not only could the yearly yield of commercial exploitation in North America be greatly increased but the harvesting could also be extended to many other sites on other continents.

3 Optimization of the use of brine shrimp cysts

Despite the present limited supply of *Artemia* cysts, their use is far from optimal. In most cases, survival from hatching is poor. One factor which contributes to this poor survival is inefficient separation of nauplii from the hatching debris. Feeding of nauplii to predators is not always at the appropriate larval stage, and efficient techniques for high-density culturing of *Artemia* larvae are not available.

It is considered that important benefits can be obtained by the application of several recent findings and new techniques.

3.1 *Hatching cysts*

Various hatching devices are commonly used: *eg*, rectangular boxes; water baths, and plastic vats with flat or funnel-shaped bottoms. It originally appeared from studies on *Artemia* that the cysts can be hatched out within a wide range of temperature, salinity and oxygen concentration (Sorgeloos and Persoone, 1975). Therefore, it was considered that the hatching of cysts at high densities did not require any standardization or special control. However, from the scarce data available it now appears that the hatching efficiency obtained with the various devices in common use is low and does not exceed an output of 50% from cyst to larvae in most cases. The principal rules which guarantee maximum hatching efficiency have now been summarized by Sorgeloos (1975) and Sorgeloos and Persoone (1975) as follows:

(*i*) Hatching rate is dependent on temperature and salinity, and hydrated cysts must be kept under strictly controlled conditions in order to obtain a maximum number of nauplii within a well defined immersion period.

(*ii*) Cysts must be kept in suspension in oxygen-saturated sea water. Cysts accumulating on the bottom of hatching apparati will often be exposed to anaerobic conditions and do not hatch under these conditions.

(*iii*) Hydrated cysts must be illuminated for specific time periods after immersion in order to trigger cyst metabolic activity. The critical triggering period differs from one strain to another (*eg*, 10 minutes at 2 000 lux for cysts from Great Salt Lake and only 5 minutes for cysts from San Francisco Bay).

(*iv*) Maximum cyst densities for optimal hatching efficiency are approximately 12–15 g/l. At higher cyst densities, the vigorous aeration needed to keep the water saturated with oxygen affects the larvae mechanically and leads to mortality.

The following standard procedure is proposed for hatching cysts. Densities of about 10 g cysts/l are hatched out in natural sea water in transparent cylindrical tubes with a funnel-shaped bottom. Continuous aeration from the bottom of the cylinder keeps all the cysts in suspension and a few drops of a non-toxic antifoam additive should be used. The cylinder is illuminated by a fluorescent light tube for 1 hour after immersion of the cysts and water temperature is kept constant at 28°C. This technique has been applied for many years in the laboratory giving hatching percentages of 70% with Great Salt Lake cysts, and as high as 90% with San Francisco Bay cysts, which means a harvest of approximately $2{\cdot}5 \times 10^6$ nauplii/l of water.

As compared to results from literature, the proposed technique gives much better hatching efficiences with considerably higher cyst densities in inexpensive and simple hatching cylinders. This results not only in more economic use of brine shrimp cysts but also, as the hatching density can be increased by a factor of 10 compared to other techniques, in an important saving of manpower and equipment (pumps, heaters, water *etc*).

3.2 *Harvesting hatched nauplii*

As empty cyst shells and non-hatched cysts can be harmful when ingested by young fish or crustacean larvae, free-swimming *Artemia* nauplii are most often separated from the remaining debris immediately after hatching.

To date, the technique utilized in most mariculture farms to separate cysts from larvae is quite primitive: after hatching, the aeration is turned off in order to separate the sinking cyst shells from the swimming nauplii. After a certain period of time (which can be up to 75 minutes), and sometimes after concentrating the phototactic larvae around a light source, the suspension containing the swimming nauplii is drained off.

Immediately after the hatching peak, the associated bacterial flora consumes more than 50% of the oxygen in the hatching medium in a few minutes. In order to avoid oxygen depletion with subsequent mortality of the most sensitive larvae, the medium is always renewed prior to separation by filtering off the whole suspension on a plankton gauze, rinsing it a couple of times, and resuspending it in fresh sea water.

The separation efficiency (qualitative and quantitative) can be greatly increased by using a cylindrical separator box as described by Sorgeloos and Persoone (1975).

It was discovered recently that the outer layer of the cyst shell, which contains haematin, can be removed by an oxidation technique. This may eliminate the need for separation of cyst shells from larvae, as the remaining hatching debris would only consist of very thin transparent membranes which might be harmless to the predators of *Artemia* nauplii. This possible application is now being investigated.

4 Feeding brine shrimp to fish and crustacean larvae

Freshly hatched brine shrimp nauplii are presently one of the best live food sources for fish and crustacean larvae. Fundamental research on the moulting rate and the energy content of the non-fed nauplii revealed that the nauplii have to be fed to the predator as soon as possible after hatching. In fact, holding the nauplii without feeding results in a considerable decrease in their energy value; within 24 hours after hatching at 28°C, the larvae moult into the second and third larval stages which is associated with a decrease in individual weight and caloric content of 24 and 28% respectively (Remiche-Van der Wielen and Sorgeloos (in press); Benijts, Van Voorden and Sorgeloos, 1975).

In most mariculture farms, only hatched brine shrimp nauplii are fed to larvae of fish and crustaceans. However, in many cases, adult *Artemia* and older and larger larvae that have been fed on an algal diet could be a more appropriate and highly nutritive food for fish and crustacean larvae. Since it has been demonstrated by Sorgeloos (1973), Cognie (1975) and Person-le Ruyet (1976) that *Artemia* can be cultured on different types of inert foods, controlled mass culturing of their larvae is now economically feasible.

Recently an automatic culturing technique has been developed with air-lift operated raceways in which densities up to 3 000 larvae/l can be cultured up to the adult stage within two weeks (Sorgeloos, Bossuyt and Baeza-Mesa, MS). The only manual work involved is replenishment of the food container twice a week.

The use of older larvae cultured to the appropriate size as prey organisms instead of freshly-hatched nauplii has several advantages: (*i*) The quantity of cysts needed will be significantly reduced as the predator will need fewer of the larger larvae as food. (*ii*) The food quality (*eg*, protein content) of the older larvae is higher than that of the first instars. (*iii*) The predator spends much less energy in ingesting a specific biomass of older larvae or adults as compared to ingestion of an identical biomass of nauplii. (*iv*) Strains of *Artemia* whose first nauplii-stages appear to be unsuitable for mariculture purposes, *eg*, because of contamination by pollutants (Great Britain, 1967; Little, 1969; Bookhout and Costlow, 1970; Wickins, 1972) or because they are too large to be swallowed by their predators (Provasoli, 1969), can become an appropriate food for large cultured species by spreading the feeding of nauplii over a number of days (Wickins, 1972). In the case of contamination of the nauplii by a pollutant, it is clear that the relative concentration of the toxicant decreases as the organism grows. Consequently, the quantity of toxicant ingested by the predators decreases if they are fed later stages of *Artemia*.

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Chapter IV Culture of Molluscs

Oyster Culture—A World Review

J. B. Glude

Abstract
It has been projected that world demand for oysters will increase from the present production of 770 000 tons to more than 2 million tons by the year 2000. Major world producers of oysters in 1972 included the USA (41·7%), Japan (29·1%), Republic of Korea (9·3%), France (8·9%) and Mexico (5·6%).

In the United States, 40% of the total oyster production is derived primarily from 'on-bottom' culture using seed from domestic sources or imported from Japan. Alternative culture techniques such as raft culture and artificial rearing in controlled environments are feasible, but are not used for economic reasons.

Most of the food oysters in Japan are produced by variations of the 'hanging method' *ie*, raft, long-line or rack culture, while the sowing method and stick culture are of lesser importance. Raft culture, the most important of these techniques, is used in 64% of the total oyster culture area. The long-line culture technique is expected to form the basis for expanding production in Japan, as it can be used in the clean offshore waters.

Although oyster culture in the Republic of Korea has only developed since 1958, annual production exceeded 70 000 tons by 1972, and with its excellent coastal environment Korea still has potential for greatly expanded oyster production. Methods of oyster culture are similar to those used in Japan, with raft culture being ideally suited for the protected waters along the coast.

Oysters are grown 'on-bottom' in France as production is primarily for the 'half-shell' trade. Extensive mortalities have occurred recently in France with the traditional species, *Ostrea edulis* and *Crassostrea angulata*, but this problem has been substantially circumvented through importation of *Crassostrea gigas* from Japan, Canada and the USA.

The Netherlands is the second largest producer of flat oysters (*O. edulis*) after France. A recent change in the traditional culture technique in the Netherlands is to use empty shells instead of tiles as spat collectors.

Rock oysters (*Crassostrea commercialis*) are cultured with the stick and tray method in Australia. Because of the concern about the extensive area needed for this two-dimensional culture system, experiments have recently begun to test the applicability of the Japanese long-line method.

Smaller quantities of oysters are produced by various methods in other countries, including Mexico, Taiwan Province of China, Canada, New Zealand, Great Britain and Germany.

From a technical standpoint, worldwide oyster production could be increased greatly by applying methods which are currently used in some parts of the world. Among the major factors affecting the maintenance and development of oyster production are: availability of suitable space and environmental conditions (water of good quality, natural food supplies, *etc*); suitable seed supply; selection of suitable species and genetic improvement of stocks; provision of feeds for artificial or intensive culture systems; control of diseases, predators and fouling organisms; and type of harvesting method.

Ostréiculture: revue mondiale
Résumé
On prévoit que la demande mondiale d'huitres augmentera, la production passant du chiffre actuel de 770 000 tonnes à plus de 2 millions tonnes en l'an 2000. En 1972, les principaux producteurs étaient les Etats-Unis (41,7%), le Japon (29,1%), la République de Corée (9,3%), la France (8,9%) et le Mexique (5,6%).

Aux Etats-Unis, 40% de la production totale d'huîtres provient en premier lieu de l'élevage 'sur le fond' qui utilise du naissain d'origine domestique ou importé du Japon. D'autres techniques telles que la culture sur radeau et l'élevage artificiel dans un environnement contrôlé sont possibles, mais ne sont pas utilisées pour des raisons économiques.

Au Japon, la production ostréicole repose généralement sur l'une des variantes de la méthode par suspension, c'est-à-dire sur radeau, sur palangre ou sur claie, tandis que les méthodes d'ensemencement et d'élevage sur pieux ont moins d'importance. La culture sur radeau, la plus importante des techniques utilisées, occupe 64% des superficies totales de l'ostréiculture. La technique d'élevage sur palangre devrait former la base de l'expansion de la production japonaise, car elle peut être employée dans les eaux propres du large.

Si l'ostréiculture ne s'est développée que depuis 1958 en République de Corée, la production annuelle a excédé 70 000 tonnes en 1972, et grâce à son environnement littoral excellent, la Corée dispose encore d'un potentiel considérable pour l'expansion de cette production. Les méthodes d'ostréiculture sont analogues à celles utilisées au Japon, la culture sur radeau convenant parfaitement aux eaux protégées qui longent les côtes coréennes.

En France, les huitres sont elevees en parcs, la production etant essentiellement destinée au commerce de l'huitre en coquille. Des taux de mortalité considérables ont récemment frappé les espèces traditionnelles *Ostrea edulis* et *Crassostrea angulata*, mais l'on a largement surmonté ce problème en important l'huître *Crassostrea gigas* du Japon, du Canada et des Etats Unis.

Les Pays-Bas sont par importance le second producteur d'huitres plates (*O. edulis*) après la France. La technique traditionnelle de culture s'est modifiée récemment aux Pays-Bas, où l'on utilise des coquilles de moules vides au lieu de tuiles comme collecteurs.

En Australie, on élève l'huitre (*Crassostrea commercialis*) sur pieux et sur claies. Etant donné que ce système d'élevage bidimentionnel nécessite une vaste superficie, des expériences ont récemment eu pour objet de vérifier la possibilité d'appliquer la méthode de culture japonaise sur palangre.

Les huitres sont également produites en petite quantité par diverses méthodes en d'autres pays et notamment au Mexique, en Chine (Prov. Taiwan), au Canada, en Nouvelle-Zélande, en Grande-Bretagne, et en Allemagne.

D'un point de vue technique, la production mondiale d'huitres pourrait être grandement accrue par l'application des méthodes qui sont actuellement utilisées en certaines parties du monde. Parmi les principaux facteurs affectant le maintien et le développement de la production huitrière l'on peut citer l'existence d'endroits et de conditions environnementales adéquates; des sources convenables de produits d'ensemencement, la sélection d'espèces adaptées et l'amélioration génétique des stocks; l'approvisionnement en aliments pour les systèmes de culture artificiels ou intensifs; le contrôle des maladies des prédateurs et des organismes de fouling; et de type de méthode de récolte.

Ostricultura: retrospección mundial
Extracto
Se ha estimado, sobre la base de algunas proyecciones, que la demanda mundial de ostras aumentará para el ano 2000 de las actuales 770 000 toneladas a más de 2 millones. Los principales países productores de ostras en 1972 fueron Estados Unidos (41,7%), Japón (29,1%), Republica de Corea (9,3%), Francia (8,9%) y México (5,6%).

En los Estados Unidos, el 40% de la producción total de ostras procede ante todo del cultivo sobre el fondo, utilizando semillas de fuentes locales o importadas del Japón. Son también posibles otras técnicas de cultivo, como el cultivo en balsas y la cria artificial en medios controlados, pero no se utilizan por razones económicas.

La mayoria de las ostras destinadas al consumo humano en el Japón se producen con distintas variaciones del método de cultivo en suspensión—cultivo en balsas, palangres o bastidores—, mientras el método de siembra por dispersión y el cultivo en varas tienen menor importancia. La más importante de estas técnicas es la de cultivo en bastidores, que se utiliza en el 64% de la superficie total dedicada a la ostricultura. Se espera que el cultivo en palangres sirva de base para la expansión de la producción, ya que puede utilizarse en aguas limpias de mar abierto.

Aunque el cultivo de ostras en la República de Corea comenzó sólo en 1958, para 1972 la producción anual superaba ya las 70 000 toneladas. Dado que su medio ambiente costero es excelente, Corea tiene aún grandes posibilidades para incrementar su producción de ostras. Los métodos de ostricultura son análogos a los utilizados en el Japón, y el cultivo en balsas resulta ideal en las aguas protegidas a lo largo de la costa.

En Francia, las ostras se crian sobre el fondo, ya que la producción se destina sobre todo a la venta 'de una concha'. Recientemente se han registrado grandes mortandades de las especies tradicionales, *Ostrea edulis* y *Crassostrea angulata*, pero se ha conseguido evadir sustancialmente este problema importando *Crassostrea gigas* del Japón, Canadá y los Estados Unidos.

Los Países Bajos son el segundo productor de ostras planas (*O. edulis*) después de Francia. Recientemente se ha introducido un cambio en la técnica tradicional de cultivo de los Países Bajos, utilizando como colectores para las larvas conchas vacias de mejillón en vez de tejas.

En Australia se cultivan ostras de roca (*Crassostrea commercialis*) con el método de varas y bandejas. Dada la preocupación por las vastas superficies que son necesarias para este sistema de cultivo bidimensional, se han iniciado recientemente algunos experimentos para ensayar la posibilidad de utilizar el método japonés de palangres.

También se producen ostras, en cantidades menores, en México, Taiwán (provincia de China), Nueva Zelandia, Gran Bretaña y Alemania.

Desde un punto de vista técnico la producción mundial de ostras

podría ser aumentada grandemente mediante la aplicación de métodos que actualmente están siendo empleados en algunas partes del mundo. Entre los factores más importantes que afectan el mantenimiento y desarrollo de la producción ostrícola están: disponibilidad de lugares y condiciones ambientales adecuadas (agua de buena calidad, fuente natural de alimentos, etc.); una fuente adecuada de semilla; la selección de especies apropiadas y la mejora genética de cepas; provisión de alimentos para los sistemas de cultivos artificiales e intensivos; control de enfermedades, depredadores y organismos incrustantes; y el tipo de métodología a usarse en la recogida de la cosecha.

1 Introduction

Historically, oysters have been the major invertebrate species produced by aquaculture. Methods for oyster culture were established centuries ago and in most countries where oysters are used as food, natural production is supplemented by man's efforts.

1.1 *Oyster consumption*

Worldwide oyster consumption is about 770 000 metric tons (1 700 million pounds) round weight or more than 10% of the world production from aquaculture. The United States consumes about 60% of the world's oysters, 458 500 metric tons on a round weight basis, including about 325 600 tons from domestic production and about 133 000 tons from imports (FAO, 1973).

Oyster consumption in the United States has varied little from 1947 to the present, but domestic production has decreased—first in response to imports from Japan, and more recently from the Republic of Korea and other countries (NMFS, 1947 to 1973).

1.2 *Projected demand*

Bell, *et al* (1970), projected the world aggregate consumption for oysters as increasing to more than 2·45 million tons (5 409 million pounds) by the year 2000. These authors project a demand for oysters in the United States as increasing from the present level of about 458 500 tons round weight to 727 400 tons by the year 2000.

2 Present status of oyster culture

Major oyster-producing countries listed in order of decreasing production are the United States, Japan, Republic of Korea, France, Mexico and Taiwan Province of China (Table I). Many other countries produce smaller quantities of oysters, mainly for domestic use.

2.1 *United States*

In the United States, 60% of the oyster production comes from natural stocks on state-owned inter-tidal or sub-tidal beds harvested by licensed fishermen. Some states manage the public oyster fishery to achieve maximum sustainable yields following the same procedures used for management of finfish stocks. Other states supplement natural production by placing shells or other materials in the water to collect spat, and transplant seed oysters to public growing grounds for subsequent harvest by licensed fishermen.

About 40% of the United States oyster production comes from privately owned or leased inter-tidal or sub-tidal oyster beds. Nearly all of the United States production from private aquaculture is based on growing oysters on-bottom using seed from domestic sources or imported from Japan. Although the raft culture methods used in Japan, Republic of Korea and other countries are well known in the United States, the economics of oyster culture necessitate minimizing production costs. Since oyster culture on-bottom is less costly in the United States than off-bottom culture and since adequate areas suitable for oyster culture have been available, there have been only a few sporadic attempts at raft culture in certain areas. With the projected increase in demand and the increasing limitations on aquaculture in the coastal zone, raft culture methods may become necessary in the United States.

The use of hatcheries to produce seed oysters is increasing in the United States. The supply of seed oysters from natural reproduction is decreasing in many places because of environmental degradation, and the cost of imported seed is increasing. Under these conditions oyster hatcheries are becoming economical. In 1975, there were 19 oyster hatcheries in the United States of which 7 were designed for research. Although several of these hatcheries produced seed oysters attached to oyster shells for use in traditional culture systems, most produced unattached or 'cultchless' seed which must be reared in trays until large enough to be planted in inter-tidal or sub-tidal areas. Seed can be produced in hatcheries in the United States for approximately the same cost as that of imported seed from natural reproduction. Seed from natural sources, especially in the southern part of the United States where setting is dependable, is considerably less expensive than hatchery seed. If production methods can be perfected and if larval mortalities can be controlled, commercial hatcheries should be able to supply the increased seed needed for expansion of oyster culture to meet projected United States demands.

The Virginia Institute of Marine Science, Gloucester Point, Virginia, has developed strains of oysters which are resistant to oyster diseases using as parents the survivors of a mass mortality of oysters in Mojack Bay near the mouth of Chesapeake Bay where most of the oysters were killed by the haplosporidan *Minchinia nelsoni*. Drs. J. Andrews and John Dupuy and associates reared progeny of these oysters

TABLE I
WORLD OYSTER LANDINGS, INTERNATIONAL TRADE AND CONSUMPTION, 1972
(round weight—metric tons)

Country	*Landings*	*Exports*	*Imports*	*Apparent consumption*
United States	325 608·8	—	132 931·2	458 540·0
Japan	225 774·2	81 901·6	—	135 700·6
Korea, Republic of	72 730·8	35 775·2	—	36 955·6
France	68 871·8	—	17 978·4	86 850·2
Mexico	43 538·6	—	—	43 538·6
Other	42 312·8	33 232·8[1]	[1]	9 080·0
Total	778 837	150 909·1	150 909·6	770 664·4

[1] International trade statistics in some instances do not identify the origin and destination of products
Source: FAO (1973)

in an experimental hatchery and placed them in the Bay to test their disease resistance. After rearing a number of generations, these scientists have demonstrated several lines of oysters with significant genetic resistance to *Minchinia*. The results of these studies have indicated the practicability of genetic improvement of strains of oysters to increase disease resistance. A 'spin-off' benefit has been the development of a line of oysters with a deeper cupped shell which results in greater meat yield for oysters of a given size. In the future, significant changes can be made in the characteristics of oysters to improve their adaptability to oyster culture as well as their market acceptance.

Perhaps the most imaginative scheme for raising oysters in the United States is an experimental closed cycle shellfish factory being tested by Dr. Kent S. Price, Jr. and his associates at the University of Delaware. This project was developed as an alternative to oyster production in Delaware Bay which had decreased from 4 086 tons of oyster meat in 1950 to less than 454 tons by 1970 because of several factors. As industrial and residential development increased, the Bay's watershed was deforested and more water ran off the land into the Bay, bringing with it greater loads of silt. In addition, the introduction of pesticides, especially those to control salt marsh mosquitoes, and increasing oil pollution contributed to the drastic decline of the oyster population. The final blow was an epidemic disease caused by *Minchinia nelsoni* which caused a catastrophic collapse of the Bay's oyster industry in the late fifties and the early sixties.

The University of Delaware project, based in one large building, maintains oysters and clams in a rigidly controlled environment from the time of egg release to market size. The larvae and juveniles are fed diets of algae which are reared in a large food production facility. The shellfish produced in this controlled environment are uniform in shape and reach market size more rapidly than do those in Delaware Bay. At the present time, the facility is being expanded from the initial capacity of four bushels (141 l) of experimental animals to 50 bushels (1 762 l). At the conclusion this stage of testing, it is anticipated that a prototype factory with a capacity of 2000 bushels (70 480 l) will be built and tested. It should then be possible to determine the economics of this intensive culture system.

In summary, United States oyster production has followed traditional on-bottom culture methods because of economic considerations. Although the demand has remained stable, an increasing share of the market has been taken by imported oysters and United States growers have reduced production to meet demand levels. The price of oysters has not increased to the extent that other fisheries products have at a time when production costs generally have increased. This has resulted in a less satisfactory profit picture for many growers. In addition, the increasing demands of other users for space in the coastal zone together with a reduction in suitable areas because of degradation of water quality has discouraged expansion of oyster culture. Nevertheless, the large and stable demand for oysters in the United States, together with projected increases for the future, indicate the need for expansion of oyster production during the rest of this century. With control of production costs, improved product form, better distribution and marketing systems, oyster production in the United States could be increased to meet projected demands.

2.2 *Japan*

Oyster culture for food and for pearls has a long history in Japan and many of the methods used for oyster culture in other countries were developed or perfected in Japan. This paper considers only production of food oysters which is centred in Miyagi, Hiroshima, and Kumamoto prefectures.

Five different methods of oyster culture are used in Japan (Furukawa, 1971): raft, long-line, rack, stick and sowing methods. Most of the food oysters produced in Japan are grown by the 'hanging method', *ie,* suspended from rafts, long-lines or racks.

The raft method is used in protected areas where the water is more than 5 m deep. In 1968, the raft system was used in 64% of the area used for oyster production in Japan. The best oyster-producing area in Japan for raft culture is the Seto Inland Sea where rafts are protected from storms. Here there are wide areas which enable growers to use large size rafts, 20 m × 10 m.

The long-line system consists of horizontal lines at or near the surface from which strings of seed oysters are suspended. The horizontal lines are attached to a series of wooden barrels or metal drums to provide flotation, and the ends of each line are anchored by two anchors. The long-line system is practised in offshore grounds, principally along the northern parts of Japan, since this method can withstand rough seas which might destroy rafts. This method makes it possible to extend oyster culture into deeper waters or unprotected areas. In 1968, the long-line system was used in 11·6% of the oyster culture area in Japan, and the trend is toward increasing use of this method.

The rack method of oyster culture is generally used in shallow waters where part or all of the oysters are exposed at low tide. The rack structure consists of vertical poles or posts driven into the bottom which support rows of horizontal poles. Strings of seed oysters are suspended from the horizontal poles. The length of the strings is so arranged that the lowermost oysters do not touch bottom, which excludes crawling predators, such as oyster drills. Until several years ago, the rack method was widely used because there were extensive shallow water areas in Japan suitable for this type of culture. Now, with the development of industry in the coastal zone and degradation of water quality, the area suitable for rack culture is decreasing. At the present time this method is used principally for the collection and hardening of seed oysters in the Seto Inland Sea and in Matsushima Bay. In 1968, rack culture was used in 8·6% of the area used for oyster culture in Japan, but the trend is downward.

The sowing method, in which oysters are placed directly on the bottom, is an old system with low productivity and is used only for the suminoegaki (*Crassostrea rivularis*) in the Ariake Sea. This method is used in 6·9% of the area under oyster cultivation in Japan.

The fifth method, stick culture, is an older method which has many of the disadvantages of the sowing method since the growing oysters are not protected from crawling predators. In this method seed oysters are attached to wooden sticks driven into the bottom in the inter-tidal zone. Like rack culture, this method is decreasing in popularity because of the lack of suitable areas in shallow water. In 1968, this method was used in 8·6% of the growing area in Japan, primarily in the East China Sea.

By far the most progressive methods of oyster culture

used in Japan are the raft and the long-line systems. Both maximize production per unit of area and minimize losses from predation. The economics of oyster culture in Japan permit the use of these methods even though they are labour-intensive.

In Japan, adequate quantities of seed oysters can be collected to supply the domestic industry and to export to the United States, France and some other countries. The centre of seed production is Matsushima Bay in Miyagi prefecture with smaller quantities from Fukushima, Hiroshima and Kumamoto prefectures. Because of the availability of seed oysters from natural reproduction, seed oyster hatcheries are not used in Japan even though methods for artificial propagation were developed by Japanese scientists many years ago. This situation has also resulted in a continuation of traditional culture methods based upon spat attached to oyster shells, scallop shells or to man-made collectors, as seed of this type is most satisfactory for raft, long-line or rack culture.

Seed attached to shells is less satisfactory for export than unattached or 'cultchless' seed because the weight of the 'mother' shell increases shipping costs. To overcome this disadvantage, attached spat have been physically removed from 'mother' shells before shipment, but this involves extensive labour costs. Another alternative is a collection of spat on lightweight, man-made cultch materials.

The lack of oyster hatcheries in Japan makes it impractical to improve stocks genetically to increase growth rates, improve market characteristics, or to achieve disease resistance. Unexplained mass mortalities of oysters have occurred in Japan as they have in nearly every country where oysters are raised and it may become necessary to breed selectively resistant parents to improve disease resistance in the progeny.

Oyster production in Japan increased from less than 14 000 tons round weight during the mid-forties to 265 881 tons in 1968 (Furukawa, 1971). This was followed by a decreasing trend during the early seventies, largely as a result of increased water pollution in the Seto Inland Sea and because of unexplained mass mortalities.

Expansion of oyster production will probably require increased use of the long-line methods which will permit the extension of oyster culture into clean offshore areas, especially in northern Japan, even though growth rates will be less than in the warm southern inshore waters. Export of seed oysters from Japan will undoubtedly continue, but increased production from commercial hatcheries in the United States and successful local reproduction of the Pacific oyster (*Crassostrea gigas*) in France, may reduce the quantities required. The alternative of using lightweight seed produced in Japan would be more economical than that produced in the United States, France or other countries. In this case, seed oyster production in Japan might expand considerably.

2.3 *Republic of Korea*

Oyster production in the Republic of Korea was negligible before 1958. Production increased to about 10 000 tons round weight during the early sixties, about 42 000 tons during the late sixties and by 1972, 73 000 tons. With extensive shallow bays protected from storms by surrounding hills, low labour costs and a government commitment to develop oyster culture, Korea has potential for greatly expanded oyster production.

The Republic of Korea began exporting canned oysters to the United States in 1963 (15 tons, meat weight). Exports had more than doubled by the late sixties and then increased dramatically to 635 tons in 1971, 2 500 tons in 1972, and 4 195 tons in 1973. At the same time, Japanese exports of canned oysters to the United States decreased from a high of 6 335 tons in 1967 to 2 956 tons in 1973.

Small quantities of frozen oysters were exported from the Republic of Korea to the United States beginning in 1963, but reached only 88 tons meat weight by 1973. Exports of live seed oysters or fresh shucked oysters to the United States have not been permitted because of the discovery of a haplosporidan parasite of the genus *Minchinia* in Korean oysters. Since *Minchinia nelsoni* and *Minchinia costalis* have been found to be the cause of extensive mortalities of the eastern oyster (*Crassostrea virginica*) in Delaware, Maryland and Virginia, there is apprehension that the *Minchinia* found in Korean oysters might cause extensive mortalities among *Crassostrea gigas* which is raised on the Pacific coast of the United States. Decisions regarding the export of their live or fresh shucked oysters to the United States will be withheld until present investigations are concluded.

Methods of oyster culture used in Korea are similar to those in Japan. Raft culture is ideal for their protected waters, and the labour-intensive nature of this operation is offset by low labour costs. It appears likely that oyster production in the Republic of Korea will expand greatly during the next decade unless major mortalities occur.

2.4 *France*

Oyster production in France varied from 103,583 tons in 1947 to a low of 3 810 tons in 1955, then rose to nearly 88 000 tons in 1959 to 1961, and 69 000 tons in 1972. In France, oysters are grown on-bottom because this is the best way to produce regular-shaped shells preferred by consumers of raw half-shell oysters (Bardach, Ryther and McLarney, 1972). Some oysters are now grown by the rack-culture method at Arcachon and by the raft-culture method near Thau on the Mediterranean coast (Doumenge, 1974 and personal communication, 1976). Although productivity could be increased by off-bottom culture and sale of shucked oysters, the established demand for half-shell oysters guarantees continuation of on-bottom culture.

The two major species of oysters traditionally grown in France are the flat oyster (*Ostrea edulis*) and the Portuguese oyster (*Crassostrea angulata*). During recent years, extensive mortalities of oysters have occurred in France and seed oysters have become scarce. In response to this situation, the industry has imported seed of *Crassostrea gigas* from Japan, Canada and the United States, and much of the industry is currently based on this species. Adult Pacific oysters have also been imported, resulting in the establishment of a breeding population. In 1975 enough seed was obtained from natural reproduction to supply the French market. Oyster hatcheries have been tried but to date have not proved to be economically successful.

It appears that Western Europe, and France in particular, will continue to consume large quantities of oysters, perhaps more than can be produced locally.

2.5 *The Netherlands*

P. Korringa (personal communication, 1975) reports that the Netherlands continue to be the second largest producer

of the flat oyster (*Ostrea edulis*) after France, producing about 15 million oysters weighing 1 200 to 1 500 tons in the shell. After a major mortality caused by the cold winter of 1962–63, three-year old oysters were transplanted from Brittany, France, to supply the markets in Belgium. Now breeding stocks have been reestablished in the Oosterschelde area and supply local seed in addition to stock imported each year from France.

The growth and quality of flat oysters in the Netherlands leaves nothing to be desired and mortalities have been lower than those in Brittany where extensive losses have been caused by a little known microscopic parasite. Apparently under the environmental conditions of the Netherlands, this parasite is a less important cause of mortality than in France.

Culture methods for the flat oyster have changed somewhat since the disastrous winter of 1962–1963. Tiles are no longer used as spat collectors, but instead empty mussel shells from canneries are spread on the plots, resulting in savings of labour.

Prospects are good for continuation of the oyster industry in the Netherlands. According to Dr. Korringa production could well increase to twice the 1975 level.

2.6 *Australia*

Stick and tray methods continue to be used in the culture of the rock oyster *Crassostrea commercialis* (=*C. glomerata*) since these methods maintain the oysters at the optimal tidal level to maximize growth without excessive fouling. Because of concern about the extensive area needed for this two-dimensional culture system, Australian scientists have conducted experiments to test the applicability of the Japanese long-line method. Dr. Baugham Wisely, of the Port Stephens N.S.W. Research Station, has established experimental long-line plantings in 21 selected locations from the Tweed River at the Queensland border to Wonboyn Lakes at the Victorian border. Oysters suspended from long-line arrays were found to grow quite well. Bio-fouling was a problem but it could be controlled by taking the long-lines out of the water until the fouling organisms died.

In another experiment, Dr. Wisely and his associates are investigating the applicability of the Japanese raft culture system in New South Wales.

The traditional system of collecting and growing oysters attached to tarred sticks involves high labour costs. According to Dr. P. Wolf, a better system would be to place small individual spat directly in trays in areas where waves and currents are moderate enough to permit tray culture.

Over-spatting is a problem especially in the northern rivers of Australia. Since oysters in this warm environment may spawn two to four times a year, market-sized oysters must be cleaned of small oysters which involves additional labour costs.

Several parasite and disease problems inhibit oyster culture in Australia (personal communication, P. Wolf, 1975). One of the main reasons why oysters cannot be grown permanently submerged is the presence of the annelid mudworm (*Polydora*). A so-called 'winter mortality' continues to cause heavy losses of three-year old oysters during May to September, especially during years of low rainfall and resulting high salinity. Mortalities can be reduced by raising the elevation of the trays by up to 30 cm during the crucial winter months but growth is also reduced. However, the causative organism or condition has not been identified. Other parasites of unknown importance in oyster culture in Australia include a haplosporidan of the genus *Marteilia*, the cestode *Tylocephalum* and an unidentified ovarian parasite.

2.7 *Other countries*

Many other countries produce oysters in smaller quantities mostly for domestic use but partially also for export. Mexico produces nearly 45 000 tons of oysters round weight; Taiwan Province of China more than 11 000 tons and other nations including Canada, New Zealand and the United Kingdom more than 45 000 tons.

Oyster culture methods used by various countries differ in accordance with the local environment, the species of oyster used, and the availability of space for private farming. Most of the methods used have been described in published literature and provide a variety of systems which might be applied in additional locations.

In the Federal Republic of Germany, Pacific oysters (*Crassostrea gigas*) are grown in submerged trays as replacement for the dwindling crop of native European oysters, *Ostrea edulis*. Seed oysters are placed in perforated plastic trays, 55·5 × 35·5 × 6·0 cm, held off bottom in a steel framework or container. Containers can be lifted to the surface as needed for cleaning or for harvesting the crop (Meixner, 1979).

An unusual method tried in the Pacific Islands of Palau and Fiji is the attachment of 3–8 mm spat to materials simulating oyster or scallop shells so that raft culture systems can be used. The high air-freight rates in the Central Pacific make it impractical to ship oysters attached to traditional collectors from Japan, the United States, Australia or New Zealand. Unattached or 'cultchless' seed from commercial hatcheries in the United States can be shipped economically by air-freight with low mortality rates. The low labour costs in most Pacific Islands make it practical to glue the small spat to squares of Masonite or other man-made materials which can then be strung on wire or rope and suspended below rafts (Glude, 1972).

3 Major problems of oyster farming and possible solutions

Private farming of oysters is well established in many countries and methods have been developed to suit various species of oysters, various environments and local markets. Harvesting, processing and marketing procedures have also been well developed in most areas. From a technical standpoint, worldwide oyster production could be increased greatly by applying methods which are currently being used in some parts of the world. However, there are various factors which prevent, limit or delay expansion of oyster production. The following discussion will concern principally the problems of expanding oyster production in the United States, but many of the limiting factors will apply wherever oysters are farmed.

3.1 *Site selection*

3.1.1 *Space for private oyster culture in suitable environments.* Expansion of oyster culture in the United States is limited because of the difficulty of obtaining control of adequate space in bays or estuaries for private oyster farming. In some parts of the United States, such as New England, public ownership and public use of waters and tidelands are traditional and it is difficult for individuals or

firms to obtain adequate space for aquaculture. In other parts of the United States, such as the Pacific Northwest, the importance of aquaculture was recognized many years ago and systems were developed for allocating space to individuals or firms for growing oysters, clams and other organisms.

The growing demand for space in the coastal zone for industries, residential or recreational purposes, and the increasing control of activities in the coastal zone under federal and state laws, will make it difficult to obtain adequate areas for aquaculture.

With the increasing need for food production by aquaculture as wild stocks reach or exceed maximum sustainable yield levels, a national policy is needed to recognize the importance of allocating space in the coastal zone for farming of fish and shellfish. The importance of food production in the near-shore environment has been recognized in Japan, the Republic of Korea and many other countries, and space has been allocated for aquaculture.

3.1.2 *Water quality.* Oyster farming requires high water quality because of the danger of transmitting diseases in products which are likely to be eaten without cooking. In the United States and in many other countries, areas once suitable for oyster culture have become unusable because of domestic or industrial pollution. Pollution control is needed at the local and national level to protect clean areas which are important for food production, and reduce contamination in other areas so that oyster farming can be re-established.

3.1.3 *Natural food supplies*
One of the problems in site selection, especially in areas that have not previously been used for oyster farming, is to find locations with adequate natural food supplies to ensure rapid growth and adequate fattening. Many areas, especially in the tropics, lack adequate nutrients to support growth of those species of algae which are utilized by oysters. Although food levels can be estimated from examination of plankton, test plantings of oysters are usually necessary to determine the adequacy of natural food supplies.

3.2 *Seed supply*
3.2.1 *Fluctuations in natural setting.* Natural setting of oysters varies with location and season. In some places such as New England, setting may be below maintenance levels for several years resulting in declines in oyster production. Application of improved methods such as suspension of the collectors below rafts may achieve better utilization of natural seed supplies. Another method known as 'seed banking' has been tried in the Pacific Northwest where setting of the introduced Pacific oyster (*Crassostrea gigas*) occurs only during warmer years. In this method, seed collecting during a year of successful setting is purposely stunted by placing it high in the inter-tidal zone. The seed is then available for planting on growing grounds in succeeding years.

3.2.2 *Artificial propagation.* Oyster hatcheries based generally on methods developed by the National Marine Fisheries Service (formerly the Bureau of Commercial Fisheries) laboratory at Milford, Connecticut, are now in use in the United States and are producing increasing quantities of seed for domestic use and for export. Twelve production hatcheries were in operation in 1975; about half producing *Crassostrea virginica* and about half producing *C. gigas*. Although most of these hatcheries can produce unattached or 'cultchless' seed, demand especially on the Pacific Coast is largely for spat attached to conventional collector materials such as oyster shell. This seed is adaptable to traditional oyster culture methods, but it is too heavy to permit economical transportation except for short distances. Unattached or 'cultchless' seed has the advantage of light weight which permits economical air shipment; however, use of this seed requires specialized culture techniques. Some oyster farmers, especially on the Atlantic Coast, are now changing their procedures to permit use of unattached seed and it is likely that this practice will expand.

3.3 *Genetic improvement of stocks*
The increased use of hatcheries to produce seed supplies makes it possible to apply selective breeding techniques such as those used in animal husbandry, to develop improved strains of oysters. The Virginia Institute of Marine Science has already developed several strains of oysters with increased disease resistance. Preliminary experiments have indicated a possibility of increasing growth rate and developing improved shell shape by genetic selection. With continuation of genetics research in university, state and federal laboratories, and application of selective breeding procedures in commercial hatcheries, there is a great potential for genetic improvement of oyster stocks.

3.4 *Species selection*
Over 100 species of oysters have been described from various environments ranging from brackish water to oceanic salinity, and from tropical to near arctic temperatures. From these species one can select oysters which will survive in nearly any estuarine or marine environment. However, adequate growth, fattening and successful reproduction may occur only in certain areas.

As a general principle, native species should be used whenever possible to avoid the transfer of predators, parasites and diseases or the introduction of species which will replace more desirable local forms. It may be possible to improve the growth, fattening or general marketability of native species by selective breeding or by limiting culture to certain advantageous localities.

In some places it may be necessary to introduce exotic species where there are no oysters at the present time, or where the native species are not suitable for commercial culture. In such cases it is preferable to transplant seed oysters which have been produced in hatcheries to minimize the possibility of introducing predators, parasites or diseases. Where this is not possible, seed for transplanting should be carefully inspected by qualified scientists to reduce the likelihood of introducing unwanted species or diseases.

3.5 *Feeding*
Feeding of oysters is generally not a problem since they are able to utilize naturally occurring phytoplankton populations. However, it is important to select areas for oyster culture in which natural food supplies are adequate.

Intensive oyster culture systems, such as that being developed at the University of Delaware, require production of suitable species of algae for feeding larvae and

juveniles. Methods for algal culture are fairly well known, but the problem of producing large quantities of algae at economical costs has not been resolved. An alternative is the development of an artificial food in pellet form such as that used for trout, catfish or salmon, but manufactured to meet the 2–10 micron size required for oysters. Although artificial foods meeting these physical specifications have been developed, none so far has equalled live algae in nutritive value to the oyster.

Another alternative is to include oysters in polyculture systems where nutrients from the culture of other species could be used to stimulate the growth of algae.

3.6 *Environmental management*

Satisfactory water quality is a primary requirement for oyster culture. Administrative and enforcement activities are needed at the local and national level to prevent degradation of water quality in areas needed for culture of oysters and other shellfish. An associated problem is the control of effluents produced in the aquaculture of oysters and other species. United States environmental agencies consider aquaculture systems which discharge waters into the natural environment as a potential source of pollution. Waste water from such systems must be treated to reduce suspended solids and biochemical oxygen demand to acceptable levels. Culture of oysters and other shellfish on-bottom or suspended below rafts in bays and estuaries have not yet been required to meet effluent control standards.

3.7 *Control of diseases, predators and fouling*

3.7.1 *Diseases.* Mass mortalities of oysters, often due to unexplained causes, are known to occur wherever oysters are grown and there are only a few cases where the causative organism or condition has been identified. Sindermann (1974) lists ten recognized oyster diseases in the United States, Canada and Japan, including one caused by virus, two caused by bacteria, two caused by fungus, two caused by protozoans, one caused by a parasitic copepod and two from unknown causes. Mass mortalities of oysters have also been reported in France, England, Australia, Tahiti and elsewhere.

The widespread occurrence of oyster mortality and its disastrous effect make it important to organize multinational efforts to identify causes and to develop treatments and preventive measures.

3.7.2 *Predators.* Macro-predators such as boring gastropods (oyster drills), starfish and crabs may cause extensive losses in commercial farming of oysters. Control methods usually involve proper site selection, fencing or modified culture methods such as raft or long-line systems.

3.7.3 *Fouling organisms.* Bio-fouling can be a serious problem especially in raft culture where the mother shells with attached spat are suspended close to the surface. In such cases the shells are attractive settling areas for various species of plants, barnacles, mussels and other organisms. Suggested control methods include immersion for a short time in saturated salt solution followed by drying. In some cases, fouling can be reduced by providing shade from direct sunlight. Another alternative used experimentally in the Palau Islands by the Micronesian Mariculture Demonstration Center was to surround oyster rafts with a net enclosure and to stock the pens with herbivorous rabbit fish (*Siganus* spp.) (personal communication from J. McVey, 1974).

3.8 *Harvesting methods*

Methods for removing oysters from growing areas range from picking by hand at low tide to the use of mechanized hydraulic harvesters. Special methods for harvesting raft-cultured oysters have been developed in Japan. Harvesting methods must be carefully selected since this operation represents an important expense in oyster farming.

3.9 *Economics*

On a worldwide basis, oyster farming yields a valuable food product with increasing demand. In the United States production has decreased during the last quarter century even though population has expanded; increased needs are being met by imports. Expanded imports of oysters produced at lower prices in foreign countries have held down the price of oysters and reduced the profit incentive for oyster culture.

It is estimated that the demand for oysters in the United States will increase moderately during the next decade or two. Domestic production could be increased by a factor of two to ten if prospects for return on investment were adequate, easily supplying enough oysters for the projected demand. Traditional on-bottom culture using natural seed will continue to predominate since oysters can be produced at a lower cost using this method rather than more labour-intensive off-bottom systems. Limiting factors will be the availability of space in suitable areas and maintenance of high water quality in bays and estuaries.

4 Conclusions

Oyster farming methods have been well established and a viable aquaculture industry exists in many countries. New methods, including intensive culture systems in which oysters are raised from the egg to market size in factories, are being developed on an experimental basis but the economic feasibility of such ventures has not been determined.

The use of hatchery-produced seed is increasing in the United States and this will lead to genetic improvements. Several disease-resistant strains have already been developed.

Processing, distribution and marketing procedures have been well established and standardized methods are available to provide consumers with a high quality, safe product. In practice, continual monitoring and enforcement are needed to keep those oysters which are raised in contaminated areas or processed in less than satisfactory facilities from reaching the consumer.

The demand for oysters, especially in the United States, has stabilized even though the population has expanded. Increasing the market for oysters will require improvements of product form, year-round availability, good quality control and market development activities primarily by industry. The economics of oyster culture in the United States are somewhat questionable because of the stable price which has partially been caused by increased imports of oysters produced at lower cost and by increasing production costs in the United States.

Oyster production could be greatly increased throughout the world by using methods which have been developed

and tested in various parts of the world and if financial incentives are adequate.

Research and development needs include: genetic improvement of stocks for aquaculture, identification of causes of disease and development of control methods for predators, parasites and diseases.

The worldwide importance of oyster mortalities suggests the need for development of a multi-nation effort to identify causes of oyster mortalities and to find solutions, treatments or preventive measures.

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The Status of Pacific Oyster Culture in Japan

A. Koganezawa

Abstract

The culture of the Pacific or Japanese oyster (*Crassostrea gigas*) developed in Japan from methods originating at Hiroshima and continued for more than two centuries without important modifications. Five methods are now used in Japan: raft, rack and long-line (all so-called 'hanging methods') and the more primitive stick and bottom sowing methods. Oyster culture in Japan is of two types: seed production (for internal use and export, particularly to the USA and to France), and production for food.

Site selection is determined by local ecological conditions: (*i*) the farming bed must be protected against wind and wave action; (*ii*) adult oysters which produce the necessary spawn must be close by; (*iii*) tidal and current flow must be sufficient to change the water on the bed; (*iv*) salinity must be about 27 ppt (range 19–33 ppt); (*v*) the water must contain adequate nutrients for plankton production, especially that of phytoplankton, suitable for oysters and their larvae; (*vi*) except where hanging methods are used, the bottom must be flat and free of enemies; and (*vii*) the water temperature must be within 10–30°C.

The bottom sowing method, the simplest one, requires a hard bottom, otherwise the shells are easily buried. It has low productivity and is little practised now. Similarly, stick culture has diminished in importance. Hanging culture which started in 1923 has now become by far the most important type of oyster culture in Japan. Figure 1 illustrates some of the principal oyster culture methods in Japan and Table I shows the differences in production from the five methods of culture.

Hanging culture has certain advantages over the other types: (*i*) the crop per unit area of sea bottom is increased; (*ii*) more food can be ingested by the oysters because the water supply is continuous, and the growth rate is doubled; (*iii*) as the type of bottom or depth of water is unimportant, the culture area is less restricted; (*iv*) the oysters can be cultured in clean, unpolluted water and the meat is of higher quality; (*v*) the oysters are out of reach of predators.

Rafts are used for production of seed and adults. A typical raft consists of 10–15 m wooden poles laid parallel about 0·5 m apart and fastened with wire to lateral beams. The latter are used to suspend the seed oysters. Eight to twelve floats, usually of polyethylene, are generally used and more must be added as the weight of oysters grows. The rafts are fastened end to end in series and anchored fore and aft.

Long-line culture, a modification of raft culture, can weather rough seas best of all. A typical long-line is 70–75 m long and secured at each end with two anchors. It consists of about 12 polyethylene floats connected by two parallel polyethylene ropes 2 cm in diameter, and about 60 cm apart. A series of strings of oysters (called 'rens') about 7·5 m long are hung from the parallel ropes.

The rack method, a shallow water adaptation of the hanging method, is used for both adult and seed oyster production. Wooden poles, driven into the bottom 2–4 m apart, are connected by horizontal poles which support suspended strings of cultch placed 30 cm apart.

Oyster growers in Japan have several kinds of culture grounds: seedlings, hardening, growing and fattening. Varying cultural activities at different seasons and in different areas are shown in Figure 2. Recent advances in techniques are concerned mainly with earlier fattening and harvesting.

After summer spawning, oyster meat is of poor quality; therefore oysters are harvested from October to March and the harvest is continued for canning until May. Following harvest, the oysters are shucked by hand, packed in 20 kg plastic containers and sent to the Tokyo fish market. They are kept under refrigeration (at less than 10°C) for 1–2 days. Most oysters in Japan are eaten raw but they are also processed into extract and fried, frozen, canned and smoked.

Among dangers to oysters are: (*i*) abnormally high water temperature and high salinity; (*ii*) abnormally low water temperature and low salinity; (*iii*) insufficient food; (*iv*) predators and parasites including the mudworm (*Polydora*), flatworms, oyster drills and hydroids; (*v*) disease; and (*vi*) pollution. Mass mortalities appear to be coincidental with the development of the hanging method and also connected with advanced eutrophication.

Oyster culture enterprises are usually owner-operated. The manpower necessary depends upon location, type of culture and technology involved. Culture is divided into boat work and shore work. Yields vary depending upon the method of culture and its location. The general trend of production in Japan is shown in Table III. It is difficult to determine the average cost of producing a given unit of oysters.

Situation de la culture de l'huître du Pacifique au Japon

Résumé

La culture de l'huître du Pacifique, ou huître japonaise (*Crassostrea gigas*), s'est développée au Japon sur la base de méthodes qui ont vu le jour à Hiroshima, et elle s'est poursuivie pendant plus de deux siècles sans connaître de modifications importantes. Cinq méthodes sont actuellement utilisées: la culture sur radeaux, sur claies et sur palangres (toutes méthodes dites par suspension) et les méthodes plus primitives de culture sur pieux et d'ensemencement au fond. L'ostréiculture japonaise appartient à deux types: production de naissain (pour l'usage intérieur et pour l'exportation, notamment aux Etats-Unis et en France) et production pour l'alimentation.

Le choix des sites est déterminé par les conditions écologiques locales: (*i*) le parc d'élevage doit être protégé contre l'action du vent et des vagues; (*ii*) les huîtres adultes qui produisent le naissain nécessaire doivent être proches; (*iii*) le flux de la marée et des courants doit suffire pour renouveler l'eau surjacente; (*iv*) la salinité doit être d'environ 27 ppt (gamme de 19 à 33 ppt); (*v*) l'eau doit contenir des nutriments adéquats pour la production du plancton, en particulier celle du phytoplancton qui convient aux huîtres et à leurs larves; (*vi*) sauf lorsque l'on utilise des méthodes de culture par suspension, le fond doit être plat et exempt d'ennemis des huîtres; et (*vii*) la température de l'eau doit être de l'ordre de 10 à 30°C.

La méthode d'ensemencement au fond, la plus simple, nécessite un

fond dur, faute de quoi les coquilles s'enterrent facilement. Elle a une faible productivité et elle est peu pratiquée à l'heure actuelle. La culture sur pieux a également diminué en importance. La culture par suspension qui a commencé en 1923 est désormais, de loin, le type le plus important d'ostréiculture au Japon. La Figure 1 illustre certaines des principales méthodes d'ostréiculture japonaise et le Tableau I indique les différences de production pour les cinq méthodes de culture.

La culture par suspension présente certains avantages sur les autres types: (*i*) la récolte par unité de surface du fond marin est accrue; (*ii*) les huîtres peuvent ingérer une plus grande quantité d'aliments puisque l'apport hydrique est continu et le taux de croissance est double; (*iii*) étant donné que le type de fond ou la profondeur de l'eau est sans importance, l'aire de culture est moins restreinte; (*iv*) les huîtres peuvent être élevées dans une eau propre, non polluée et la chair a une qualité supérieure; (*v*) les huîtres échappent aux atteintes des prédateurs.

On utilise des radeaux pour la production de naissain et d'adultes. Un radeau typique est formé de perches en bois de 10 à 15 m disposées parallèlement avec un espacement de quelque 0,5 m et attachées par du fil de fer à des poutres latérales. On utilise ces dernières pour y suspendre des reproducteurs. Le système est soutenu par huit à douze flotteurs, d'ordinaire en polyéthylène, et l'on en ajoute à mesure que le poids des huîtres augmente. Les radeaux sont liés ensemble en série et ancrés à l'avant et l'arrière.

La culture sur palangres, variante de la culture sur radeaux, résiste mieux que les autres méthodes à la grosse mer. Une palangre typique a de 70 à 75 m de long et est ancrée aux deux extrémités. Elle comporte une douzaine de flotteurs en polyéthylène liés à deux cordages parallèles de 2 cm de section et espacés d'environ 60 cm. Une série de chapelets d'huîtres de quelque 7,5 m de long sont suspendus à ces cordages parallèles.

La méthode de culture sur claies, adaptation en eau peu profonde de la méthode par suspension, est utilisée tant pour la production d'huîtres adultes que pour celle du naissain. Des perches en bois enfoncées au fond avec un espacement de 2 à 4 m, sont reliées ensemble par des perches horizontales auxquelles sont suspendus des chapelets de collecteurs de naissain espacés de 30 cm.

Les ostréiculteurs japonais utilisent plusieurs types de parcs selon les opérations: élevage, durcissement, croissance et engraissement. Les diverses activités exercées aux différentes saisons et en des secteurs différents sont indiqués à la Figure 2. Les progrès récents des techniques portent essentiellement sur l'engraissement et la récolte précoce.

Après le frai d'été, la chair de l'huître est de qualité inférieure; c'est pourquoi la récolte se fait d'octobre à mars; elle se poursuit pour la conserverie jusqu'au mois de mai.

Après la récolte, les huîtres sont écaillées à la main, emballées dans des conteneurs en plastique de 20 kg et expédiées au marché au poisson de Tokyo. Elles sont gardées sous réfrigération (à moins de 10°C) pendant 1 ou 2 jours. La plupart des huîtres sont mangées crues au Japon, mais elles peuvent également être transformées en extrait, ou bien être frites, congelées, mises en boîte et fumées.

Parmi les dangers qui menacent l'huître, on signale les suivants: (*i*) une température et une salinité de l'eau anormalement élevées; (*ii*) une température et une salinité de l'eau anormalement faibles; (*iii*) une alimentation déficiente; (*iv*) des prédateurs et parasites, y compris le ver polydora, les vers plats, les perceurs et les hydroïdes; (*v*) des maladies et (*vi*) la pollution. Les mortalités de masse semblent coïncider avec les progrès de la méthode par suspension, ainsi qu'avec l'eutrophisation croissante.

Les entreprises ostréicoles sont généralement gérées par leur propriétaire. La main d'œuvre nécessaire dépend du site, du type de culture et de la technologie utilisée. La culture se répartit entre des opérations à bord et des opérations à terre. Les rendements varient selon la méthode et le site. La tendance générale de la production japonaise est indiquée au Tableau III. Il est difficile de déterminer le coût moyen de production pour une unité donnée d'huîtres.

Situación del cultivo de la ostra del Pacífico en el Japón
Extracto
El cultivo de la ostra del Pacífico o japonesa (*Crassostrea gigas*) se desarrolló en el Japón a partir de los métodos utilizados originalmente en Hiroshima y se ha practicado durante más de dos siglos sin modificaciones importantes. Los métodos utilizados actualmente en el Japón son cinco: balsas, bastidores y palangres (conocidos todos ellos como 'métodos de cría en suspensión') y los métodos más primitivos de cría en varas y siembra directa sobre el fondo. La ostricultura en el Japón es de dos tipos: para producción de semilla (para uso interior y exportación, especialmente a los Estados Unidos y Francia) y para producción de alimentos.

La selección del lugar depende de las condiciones ecológicas locales: (*i*) el lecho de cría ha de estar protegido contra la acción del viento y las olas; (*ii*) ha de disponerse en proximidad de ostras adultas, que produzcan las larvas necesarias; (*iii*) el movimiento de las mareas y las corrientes ha de ser suficiente para cambiar el agua sobre el fondo; (*iv*) la salinidad debe ser de unos 27 ppt (variación: 19–33 ppt); (*v*) el agua debe contener nutrientes adecuados para la producción de plancton, especialmente fitoplancton, adecuado para las ostras y sus larvas; (*vi*) excepto cuando se utilicen métodos de cultivos en suspensión, el fondo ha de ser plano y libre de enemigos; y (*vii*) la temperatura del agua ha de ser de 10–30°C.

El método de siembra directa sobre el fondo, que es el más sencillo, exige fondos duros, ya que de no ser así las conchas se entierran fácilmente. Su productividad es baja, y actualmente es poco utilizado. También el cultivo en varas ha disminuido en importancia. El cultivo en suspensión, que comenzó en 1923, es en la actualidad el sistema más importante de cultivo de ostras en el Japón. En la Figura 1 se indican algunos de los métodos principales de ostricultura en el Japón y en el Cuadro I se muestran las diferencias en la producción con los cinco métodos.

El cultivo en suspensión tiene algunas ventajas sobre los otros tipos de cultivo: (*i*) aumenta el rendimiento por unidad de superficie del fondo marino; (*ii*) las ostras pueden ingerir más alimentos, ya que el suministro de agua es continuo, y la tasa de crecimiento se duplica; (*iii*) como el tipo de fondo y la profundidad del agua no tienen importancia, la zona apta para cultivo es menos restringida; (*iv*) las ostras pueden cultivarse en aguas limpias, no contaminadas, y la carne es de mejor calidad; (*v*) las ostras quedan fuera del alcance de los depredadores.

Las balsas se utilizan para producir semillas y adultos. Consisten de ordinario en listones de madera de 10–15 m, colocados paralelamente, a unos 0,5 m de distancia, y amarradas con alambre a viguetas laterales, que se utilizan para suspender la semilla. Generalmente se utilizan de 8 a 12 flotadores, generalmente de polietileno, y se tienen que añadir más a medida que aumenta el peso de las ostras. Las balsas están amarradas una a otra, en serie, y ancladas de proa a popa.

El cultivo en palangres, que representa una modificación del cultivo en balsas, es el que mejor resiste a la mar gruesa. Un palangre típico tiene de 70 a 75 m de longitud, y están sujetos en cada extremo con un ancla. Tienen de 8 a 12 flotadores usualmente de polietileno, unidos por dos cabos paralelos de polietileno, de 2 cm de diámetro, situados a una distancia de 60 cm. De esos cabos paralelos cuelgan otros cabos menores (llamados 'rens'), de unos 7,5 m de longitud, donde se fijan las ostras.

El método de cultivo en bastidores, que es una adaptación del método de cultivo en suspensión a aguas poco profundas, se utiliza para la producción de adultos y semilla. Se clavan en el suelo estacas de madera de 2 a 4 m de distancia, y se unen mediante varas horizontales, de las que penden cabos para la fijación de las ostras, a 30 cm de distancia uno de otro.

Los ostricultores de ostras del Japón disponen de varios tipos de zonas de cultivo: para semillas, endurecimiento, crecimiento y engorde. Las diversas actividades de cultivo según las estaciones y las zonas pueden verse en la Figura 2.

El progreso reciente de la técnicas se refiere sobre todo a la aceleración del engorde y a la recolección.

Después de la suelta de larvas en verano, la carne de las ostras es de mala calidad; por esa razón las ostras se recogen de octubre a marzo, y la recolección prosigue, para envarsarlas, hasta mayo, Después de la recolección, las ostras se desconchan a mano, se envasan en recipientes de plástico de 20 kg y se envían al mercado de pescado de Tokio. Se mantienen refrigeradas (a menos de 10°C) durante 1–2 días. En el Japón, las ostras se consumen ante todo crudas, pero también se preparan extractos y se frien, congelan, envasan o ahuman.

Entre los peligros a que están expuestas las ostras figuran: (*i*) temperatura anormalmente alta del agua y elevada salinidad; (*ii*) temperatura anormalmente baja del agua y baja salinidad; (*iii*) insuficientes alimentos; (*iv*) depredadores y parásitos, incluidos polidóridos, platelmintos, urosalpios e hidroideos; (*v*) enfermedades, y (*vi*) contaminación. Los casos de mortandad masiva parecen coincidir con el desarrollo del método de cultivo en suspensión y parecen estar también relacionados con una eutrofización avanzada.

Las empresas de ostricultura son operadas usualmente por el mismo propietario. La mano de obra necesaria depende de la localidad, el tipo de cultivo y la tecnología utilizada. Los cultivos pueden dividirse también según el método de trabajo: desde embarcaciones o desde la orilla. Los rendimientos varian según el método de cultivo y el emplazamiento. La trayectoria general de la producción en el Japón puede verse en el Cuadro III. Es difícil determinar el costo promedio de producción de cualquier unidad de ostras.

1 Introduction

Oyster culture in Japan— that of the Pacific oyster *Crassostrea gigas*— developed from the method used at Hiroshima and continued for more than two centuries without any important modifications. The original method consisted essentially of driving bamboo sticks or tree branches into the bottom of shallow water bays and inlets within their intertidal zones. Areas with a muddy bottom, areas of pure sand, those over-abundant in seaweeds, and deep water shorelines were regarded as unsuitable for oyster culture, and not used for this purpose.

Five different methods are now used for oyster culture in Japan: raft, rack, long-line, stick and bottom sowing. The so-called 'hanging methods' (raft, rack and long-line) are the most important and widely used methods. The raft and rack methods are especially popular in southern Japan; the long-line method is common along the coast of northern Japan.

. Oyster culture can also be divided into two types depending upon the purpose of culture: in the first, seed oysters are produced; in the second, the seed are reared or bought and then planted and raised to sell as a food product. Production of seed oysters is limited mostly to the Miyagi, Hiroshima and Kumamoto Prefectures; most of the growers in these areas combine seed oyster production with adult oyster culture. Seed oysters are also exported by Japan to the United States and France, where they form the basis of the edible oyster industry of the west coast of the USA and the Atlantic and Mediterranean coasts of France.

2 Oyster culture sites

In order to successfully establish an oyster farm, its location must be selected with care as determined by an appraisal of local ecological conditions. The following conditions must be fulfilled: (*i*) the farming bed must be protected against excessive winds and wave action; (*ii*) the adult oysters which produce the spawn must be present in nearby waters in sufficient numbers to ensure adequate reproduction, especially for seed oyster production; (*iii*) tidal and current flow must be sufficient to change the water of the bed; (*iv*) the salinity should be approximately 27 ‰ within a range of 19–33‰ ; (*v*) the water must contain adequate nutrients for plankton production, and must be especially rich in phytoplankton suitable as food for the oysters and their larvae; (*vi*) except in areas where hanging methods are to be used, the bottom must be flat and free from enemies of oysters; (*vii*) the water temperature must be within the tolerance range of the species, *ie*, 10–30°C.

3 Culture methods

The first phase of oyster culture is seedling production. The second phase is growing, during which the young oysters are fattened for market. Figure 1 illustrates some of the principal oyster culture methods used in Japan, and Table I shows the differences in production between the five methods of culture.

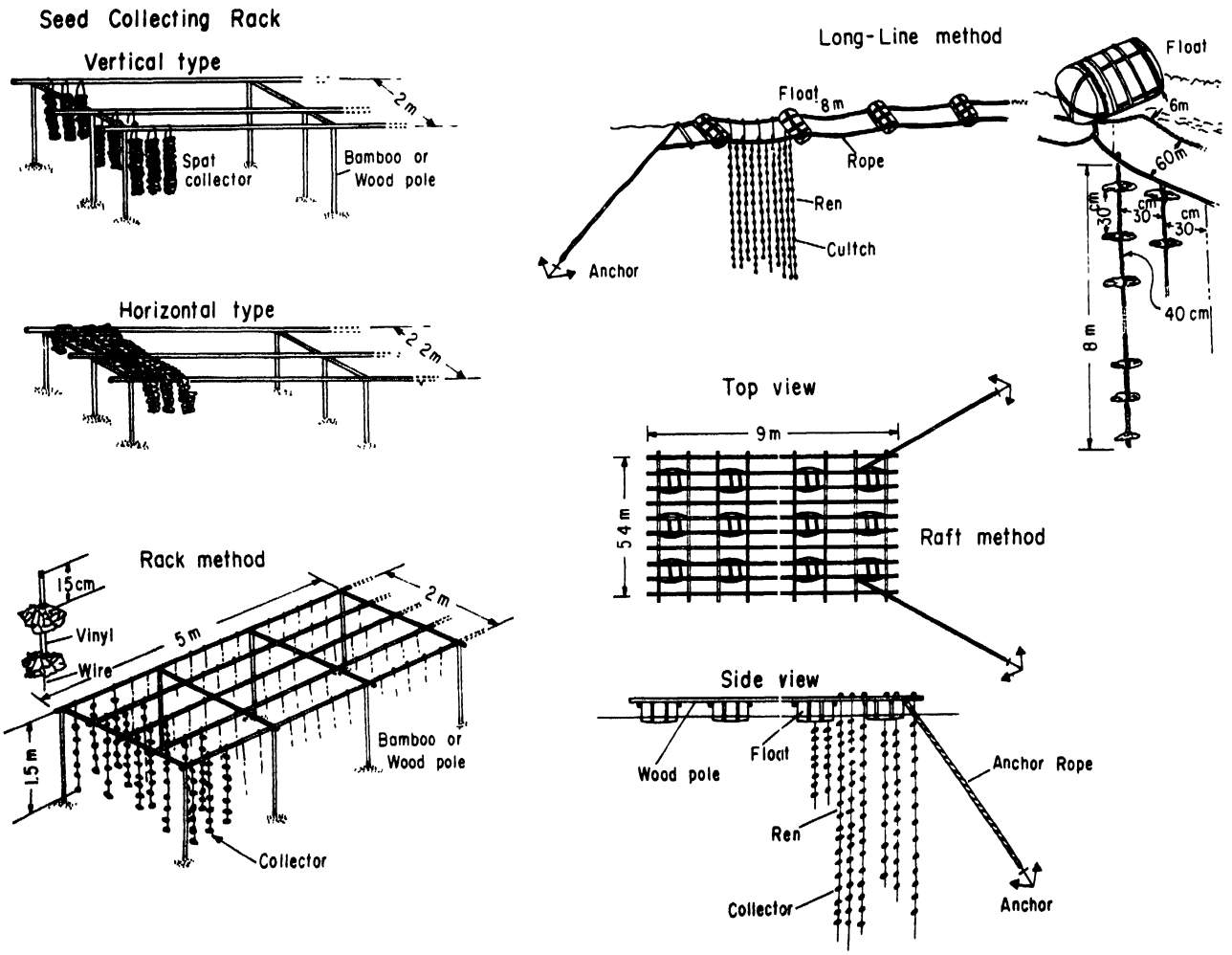


Fig 1. Oyster culture methods in Japan

TABLE I
DIFFERENCES IN PRODUCTION BETWEEN FIVE METHODS OF OYSTER CULTURE IN JAPAN

Method	*Size (m)*	*Locality and/or prefecture*	*Area (m^2)*	*No. of strings*	*No. of strings/ m^2*	*No. of cultch/ string*	*Hanging depth (m)*	*Production/ facility (kg)*	*Production/ m^2 (kg)*	*Production/ cultch (kg)*	*Production/ string (kg)*
Raft	9·1 × 18·2	Hiroshima	165·6	500	3·05	38	9·5	2 433	14·83	0·128	4·87
	4·5 × 7·3	Kamoko, Niigata	32·8	100	2·58	17	4·5	132	3·40	0·077	1·32
	6·6 × 10·0	Shizugawa, Miyagi	66·0	200	3·03	26	7·5	650	9·84	0·125	3·25
	5·4 × 9·0	Kessennuma, Kiyagi	48·6	180	3·70	17	5·0	450	9·26	0·147	2·50
Long-line	1·2 × 65·0	Ogatsu, Miyagi	78·0	280	3·59	25	7·5	950	12·18	0·136	3·39
	1·2 × 45·0	Kesennuma, Miyagi	54·0	180	3·33	17	5·0	450	8·33	0·147	2·50
Rack	2·4 × 54·0	Mangoku-ura, Miyagi	129·6	600	4·63	6	1·5	400	3·09	0·111	0·67
		Hiroshima	99·0	—	—	—	—	—	0·48	—	—
Stick	—	Hiroshima	99·0	—	—	—	—	—	0·19	—	—
Bottom sowing	—	Hiroshima	99·0	—	—	—	—	—	0·93	—	—

3.1 *Bottom sowing culture*

The 'bottom sowing method', the simplest of oyster culture methods, has been used in the Hiroshima and Kyushu districts of the East China Sea region since oyster culture began in Japan. The basic environmental qualification is that the sea bottom of the farm is hard; otherwise, in muddy areas the shells are easily buried and lost. Although sowing is a very old method, it still has practical application even in connection with the most modern culture procedures. For example, the bamboo sticks on which spat is collected are not strong enough to support growing oysters during the entire period before they reach marketable size. However, this old method has low productivity and is little practised now. Stick culture has also diminished in importance. Table II illustrates changes in oyster culture in Japan from 1964 to 1973.

3.2 *Hanging culture*

Until 1923, the culture of oysters was essentially a sea bottom industry. In that year 'hanging culture' started in Kanagawa Prefecture. This method produced excellent results for fattening oysters in the mid-water zone, an area

TABLE II
CHANGES IN OYSTER CULTURE IN JAPAN

Region	*Year*	*Production (with shell) tons*	*Total no. of growers*	*Raft*		*Long-line*		*Rack*		*Stick*		*Bottom sowing*	
				No. of growers	*No. of rafts*	*No. of growers*	*No. of long-lines*	*No. of growers*	*Area (×1 000 m^2)*	*No. of growers*	*Area (×1 000 m^2)*	*No. of growers*	*Area (×1 000 m^2)*
Total	1964	227 554	8 784	3 662	12 198	913	5 472	2 669	2 298	386	5 115	1 154	7 859
	1973	232 723	5 783	3 034	17 108	1 329	12 588	1 180	3 933	23	168	217	1 550
	73/64	1·02	0·66	0·83	1·40	1·46	2 30	0·44	1·71	0·06	0·09	0·19	0·20
Hokkaido	1964	3 595	313	5	2	94	741	107	35	—	—	107	1 010
	1973	1 546	276	—	2	159	4 340	—	—	—	—	115	1 057
	73/64	0·43	0·88	—	1·00	1·69	5·86	—	—	—	—	1·07	1·05
Pacific Ocean													
North	1964	66 335	4 075	2 125	2 958	819	4 731	823	239	—	—	308	3 563
	1973	47 355	3 387	1 531	2 116	1 162	8 208	621	351	—	—	73	32
	73/64	0·71	0·83	0·72	0·72	1·42	1·73	0·75	1·47	—	—	0·24	0·01
Middle	1964	6 927	535	255	209	—	—	280	409	—	—	—	—
	1973	3 615	330	187	912	—	—	143	1 430	—	—	—	—
	73/64	0·52	0·62	0·73	4·36	—	—	0·51	3·50	—	—	—	—
South	1964	285	93	88	76	—	—	5	5	—	—	—	—
	1973	90	37	37	51	—	—	—	—	—	—	—	—
	73/64	0·32	0·40	0·42	0·67	—	—	—	—	—	—	—	—
Japan Sea													
North	1964	9 580	332	200	578	—	—	132	—	—	378	—	—
	1973	5 155	276	180	622	8	40	88	213	—	—	—	—
	73/64	0·54	0·83	0·90	1·08	—	—	0·67	—	—	—	—	—
West	1964	1 005	362	138	201	—	—	224	86	—	—	—	—
	1973	766	164	90	78	—	—	74	158	—	—	—	—
	73/64	0·76	0·45	0·65	0·39	—	—	0·33	1·84	—	—	—	—
East China	1964	6 530	912	31	32	—	—	16	4	303	4 672	562	2 898
	1973	1 397	154	72	109	—	—	33	5	23	168	26	451
	73/64	0·21	0·17	2·32	3·41	—	—	2·06	1·25	0·08	0·04	0·05	0·16
Seto Inland	1964	133 351	2 162	820	8 142	—	—	1 082	1 520	83	65	177	389
	1973	172 800	1 159	935	13 218	—	—	221	1 776	—	—	3	10
	73/64	1·30	0·54	1·14	1·62	—	—	0·20	1·17	—	—	0·02	0·03

abundant in food but previously regarded as of no value to the oyster culturist because of its inaccessibility. This mid-water zone has now been utilized extensively; the hanging method is now the usual culture technique in Miyagi, Shizuoka, Hiroshima, Niigata and Ishikawa Prefectures.

The hanging method has certain advantages over other types of culture: (*i*) The crop of oysters per unit area of sea bottom is greatly increased as a result of vertical suspension. (*ii*) More food can be ingested by the oysters because the water supply is continuous. The resulting growth rate is about twice that obtained by other methods; consequently, even with the culture period reduced to six months, a growth can be attained which is equal to that of the sowing and stick culture methods. (*iii*) The grower can culture his oysters without regard to the character of the sea bottom or the water depth. This permits expansion of the culture area to deeper water away from the restricted shore area. (*iv*) The oysters can be cultured in clean, unpolluted seawater. The resulting meat is of much higher quality than that produced by the sowing method. (*v*) The oysters are out of reach of predators.

3.2.1 *Raft method.* The districts of Japan which have been most successful in the use of raft culture are: Hiroshima Prefecture, Kesennuma Bay in Miyagi Prefecture, and Mie Prefecture. This method is now used not only for the production of adults to be used as food, but also for the production of seed oysters for domestic use or export.

The details of raft construction vary considerably as to structure and size in the different regions. A typical raft can, however, be described as follows (Fig. 1): Wooden poles, 10–15 m long, are laid parallel to each other about 0·5 m apart and fastened by wire lashings to lateral beams. Each lateral beam is used to suspend the seed oysters from the raft. The floats for the raft are usually made from polyethylene. From 8 to 12 floats are used, the number required being determined by the weight of the hanging culture. As the oysters grow and become heavier, additional floats must be added. The rafts are fastened end to end in series, and are firmly anchored fore and aft to prevent their being carried away by wind or wave.

3.2.2 *Long-line method.* Long-line culture, developed in Miyagi Prefecture, is a modification of raft culture. This method, which is used for offshore culture along the northern coasts of Japan, can weather rough seas best of all. The basic feature of a unit for this method consists of a series of polyethylene floats arranged in a row (Fig. 1). This long-line is secured at each end with two anchors. A long-line is 70–75 m long and consists of about 12 floats connected by two parallel polyethylene ropes 2 cm in diameter. The ropes are about 60 cm apart depending on the width of the floats. A series of strings of oysters (called 'rens') each about 7·5 m long (the exact length varies with the depth of the water) are hung from each of the parallel ropes.

3.2.3 *Rack method.* The rack method is a shallow water adaptation of the hanging culture method. It is used in Miyagi, Shizuoka, Mie, Ishikawa and Hiroshima Prefectures for culture of adult oysters and is the usual method used in Miyagi Prefecture for production of seed oysters. To construct a rack, wooden poles are driven into the bottom from two to four metres apart. These uprights are connected by horizontal poles. The horizontal poles support the suspended strings of cultch, which are placed about 30 cm apart (Fig. 1).

3.2.4 *Seasonal activities of oyster culture.* The cultural activities in different seasons and in different areas are shown in Fig. 2.

The culture techniques are highly developed. The majority of the growers have several kinds of culture grounds for: seeding, hardening, growing and fattening. Each ground is used for its own special purpose. Recent advances in culture techniques are concerned primarily with earlier fattening and harvesting.

4 Harvesting

After the summer spawning, the meat of the oyster is lean and of poor quality. Therefore, the cultured oysters are harvested from October to March and for canning almost until May. After harvesting, oysters are carried to a nearby facility and shucked by hand using an iron spatula. The shucked oysters are usually packed in 20 kg plastic containers and sent to the Tokyo fish market. In order to avoid bacterial contamination, oysters are kept under refrigeration (at less than 10°C) for 1–2 days where they remain in good condition. In Japan most of the oysters are eaten raw, but there are also processed products such as: oyster extract, fried oysters, frozen oysters, canned oysters, and smoked oysters.

5 Dangers to oysters

The principal causative agents of oyster mortality are the following: (*i*) Abnormally high water temperature and high salinity. (*ii*) Abnormally low water temperature and low salinity. (*iii*) Insufficient food. (*iv*) Predators and parasites including the mudworm (*Polydora*), carnivorous flatworms and oyster drills, and hydroids. (*v*) Disease. (*vi*) Pollution.

There may be interaction of several of these, as well as with other environmental factors. Recent studies have revealed that the most important cause of mass mortality is coincident with the development of the hanging method and increase in productivity. Mass mortality is also connected with the phenomenon of advanced eutrophication in coastal waters.

6 Management

Oyster culture enterprises are usually owner-operated. The manpower needed depends upon the location, the type of culture and the technology employed. Culture operations are divided into two parts: work on boats and work on shore. The preparation of facilities used for seed collection and growing the oysters, transport of seed to the growing area and harvesting are included in the work using boats. Work on the shore includes: preparation of seed collectors, construction of rafts, and shucking and packing the harvested oysters.

Yields of cultivated oysters vary according to the method of culture and its location, but the general trend of production in Japan is summarized in Table III. However, the average cost of producing a ton or a raft of oysters is difficult to determine due to the wide range of oyster culture methods and efficiency.

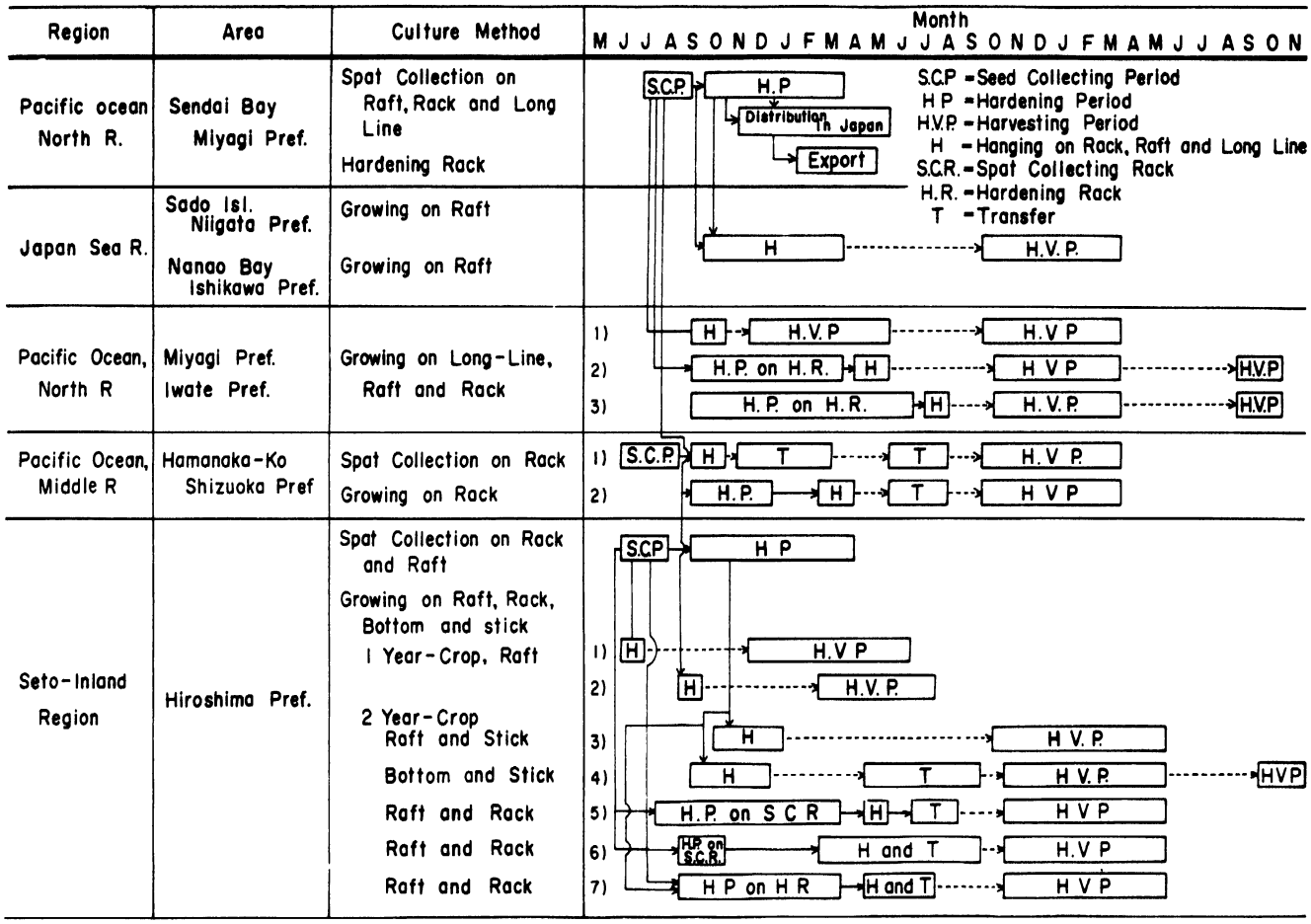


Fig 2. Seasonal activities of oyster culture in Japan

TABLE III
OYSTER PRODUCTION IN JAPAN

Year	*Production for food (tons)*			*Production of seed ×1 000 ren*[a]		
	Meat (A)	*With shell (B)*	*A/B*	*Oyster shell*	*Scallop shell*	*Other collectors*
1953	12 453	106 658	11·7			
1954	13 556	102 398	13·2			
1955	14 423	98 040	14·7			
1956	16 725	114 386	14·6			
1957	18 648	144 037	12·9	2 307	374	64
1958	20 051	151 212	13·3	1 963	483	66
1959	24 555	174 926	14·0	1 643	757	3
1960	25 977	178 276	14·6	1 534	744	41
1961	23 352	176 046	13·3	1 539	699	—
1962	30 075	214 468	14·0	1 060	634	—
1963	34 109	240 144	14·2	2 343	513	—
1964	35 221	240 564	14·6	1 448	558	—
1965	32 333	210 603	15·4	1 740	232	—
1966	35 313	221 139	16·0	2 108	496	—
1967	36 288	232 200	15·6	1 326	467	—
1968	41 798	267 388	15·6	1 872	275	—
1969	36 988	245 458	15·4	1 329	350	—
1970	35 713	190 799	13·5	1 505	329	4
1971	27 865	193 846	14·4	1 957	712	11
1972	33 861	217 373	15·6	2 931	414	4
1973	34 634	228 639	15·6	1 373	352	52

[1] The collectors are strung on 'rens' of wire, rope, etc.

Culture of Pacific Oysters (*Crassostrea gigas*) in Containers in German Coastal Waters

R. Meixner

Abstract
As replacement for a dwindling crop of native European oysters (*Ostrea edulis*), some hundred thousand hatchery-reared Pacific oysters (*Crassostrea gigas*) are now grown in containers in German coastal waters. Each oyster container consists of a steel frame fitted with up to 100 perforated plastic trays (55·5 × 35·5 × 6·0 cm). Covering 2·73 m² of sea bottom, the container offers growing space for 100 000 seed oysters, or 11 500 yearlings, or 2 500 market oysters. Fitted with legs to keep the oysters off sediment and equipped with a hauling device and a marking buoy, the container is easy to operate by using a winch on a fishing boat or on a pontoon.

Oysters raised in such conditions receive protection from exposure at low tide, predators, ice, turbulence, sediments and low oxygen. They are also protected from theft.

The traditional German fishery for *O. edulis* yielded one market oyster/3·74 m²/year. The same sea bottom area used for container culture of *Crassostrea gigas* now yields 1 000 market oysters/year.

Elevage de l'huître du pacifique (*Crassostrea gigas*) en conteneurs dans les eaux côtières allemandes
Résumé
Pour remplacer les huîtres indigènes européennes (*Ostrea edulis*), dont la production s'amenuise, des centaines de milliers d'huîtres du Pacifique (*Crassostrea gigas*) provenant d'écloseries sont maintenant élevées en conteneurs dans les eaux côtières allemandes. Chaque conteneur est constitué d'une armature en acier dans laquelle peuvent être disposés jusqu'à 100 plateaux perforés en matière plastique (55,5 × 35,5 × 6,0 cm). Avec une base de 2,73 m² sur le fond de la mer, le conteneur permet d'élever 100 000 huitres d'ensemencement ou 11 500 huitres d'un an ou 2 500 huîtres de taille marchande. Monté sur les supports pour maintenir les huîtres éloignées des sédiments, doté d'un dispositif de levage et muni d'une bouée repère, le conteneur est facilement manipulé au moyen d'un treuil installé à bord d'un bateau de pêche ou sur un ponton.

Les huîtres élevées dans ces conditions sont protégées contre l'exposition à l'air à marée basse, les prédateurs, la glace, la turbulence, les sédiments et une faible teneur en oxygène. Elles sont également protégées contre le vol.

Les élevages traditionnels allemands d'*O. edulis* produisaient une huître de taille marchande/3,74 m²/an, alors que la même superficie de fond de mer utilisée pour l'élevage de *Crassostrea gigas* en conteneurs donne maintenant 1 000 huîtres de taille marchande/an.

Cultivo de ostras del Pacífico (*Crassostrea gigas*) en contenedores en aguas costeras de Alemania
Extracto
Para sustituir a la ostra natural de Europa (*Ostrea edulis*), cuya producción disminuye continuamente, se están cultivando en zonas costeras de Alemania, en contenedores, varios cientos de millares de ostras del Pacífico (*Crassostrea gigas*) incubadas artificialmente. Los contenedores tienen un marco de acero en el que van colocadas hasta un máximo de cien bandejas perforadas de plástico (55,5 × 35,5 × 6,0 cm). Cada contenedor ocupa sobre el fondo del mar una superficie de 2,73 m² y tiene cabida para 100 000 larvas de ostra, u 11 500 ostras jóvenes de un año, o 2 500 ostras de tamaño comercial. Los contenedores, que tienen patas para evitar que las ostras entren en contacto con los sedimentos del fondo y están equipados con un gancho para arrastrar y una boya de señalar, son fáciles de manipular con un malacate instalado a bordo de una embarcación pesquera o en una plataforma flotante.

Las ostras así cultivadas están protegidas contra la baja marea, los depredadores, el hielo, turbulencias, sedimentos y nivel bajo de oxígeno. Están también protegidas contra eventuales hurtos.

La pesquería alemana tradicional de *O. edulis* dió un rendimiento de una ostra de talla comercial/3,74 m²/año. Utilizando la misma superficie de fondo marino para el cultivo en contenedores de *Crassostrea gigas* se obtienen actualmente 1 000 ostras de tamaño comercial al año.

1 Introduction

About a hundred years ago the German coast of the North Sea yielded up to 5 million European oysters, *Ostrea edulis*. The area here which was covered by wild oyster beds at that time amounted to 1 869 ha. Since 1873, a constant downward trend in the yield of these beds has been observed. Various attempts have been made to stabilize oyster production, *eg*, by completely closing the beds from 1882 to 1891, and by transplanting seed oysters of *O. edulis*. Oyster fishing became unprofitable nonetheless, and was finally stopped in 1926. Only a small production of imported European and Portuguese (*Crassostrea angulata*) oysters was kept going by growing and fattening them for one or two years before sale. In 1969, import of oysters from grounds abroad was temporarily stopped. The main reason for this was the possible danger of introducing oysters which carried pests and diseases.

Following search for a less dangerous source of seed oysters, an initial trial introduction was made in 1971 of hatchery-reared seed Pacific oysters (*Crassostrea gigas*) from a British hatchery. Together with such seed, it was necessary that a certificate be supplied affirming the absence of any known pests or diseases.

2 Field trials with hatchery-reared oysters

Owing to their small size, the seed oysters (2–8 mm) were placed on small-mesh trays which were suspended from rafts in a sheltered bay. From the very beginning, the results were so promising that the experimental introduction was repeated. The stocking was as follows: 1971, 500 individuals; 1972, 22 500; 1973, 135 000; 1974, 310 000; 1975, 390 000. At present, some hundred thousand Pacific oysters grow on the North Sea coast as well as in the Flensburg Fjord of the western Baltic, and for two years a small but increasing amount of commercial-size *Crassostrea gigas* has been on the German market.

In order to increase the yield of marketable oysters, the Institut für Küsten- und Binnenfischerei in Hamburg is cooperating with fishermen at five places along the German coast. The backbone of this programme is the use of a specially designed container (see Fig. 1). Such a container consists of a steel frame (length 210 cm, width 130 cm, height (including 50 cm legs) 130 cm) which contains up to 100 perforated plastic trays (55·5 × 35·5 × 6·0 cm inside dimension). The legs hold the trays above the bottom sediments. It is fitted with a marking buoy and a hauling device. Such a container covers 2·73 m² of sea bottom and offers 20 m² of oyster-growing space. It can be stocked with either 100 000 seed oysters or 11 500 yearlings and has space for 2 500 market oysters.

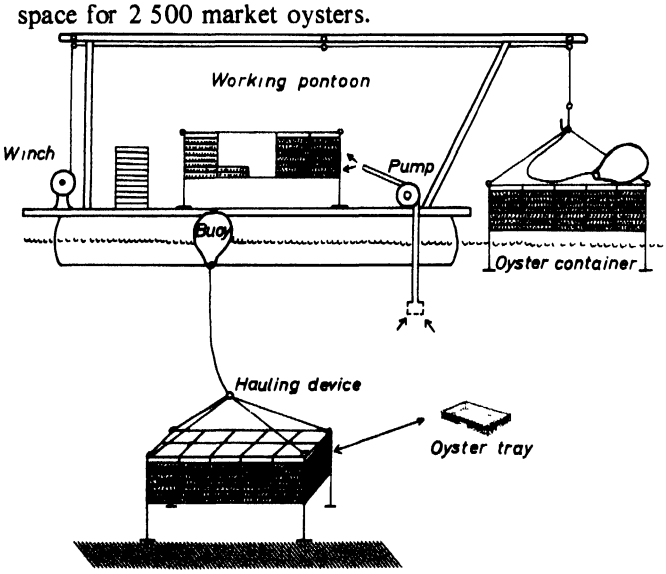


Fig 1. Schematic drawing of the use of oyster containers in the Flensburg Fjord (western Baltic)

3 Advantages of containers

Use of these oyster containers in German coastal waters offers the following advantages: (*i*) The container is easy to handle by using a winch mounted on, for example, a shrimp or mussel boat in the coastal region of the North Sea, or a pontoon in the partially sheltered waters of the Flensburg Fjord. (*ii*) The container combines the advantages of rack and tray culture with increased flexibility in handling. (*iii*) The container provides the opportunity to cultivate Pacific oysters in a submerged condition. On the German coast, where a considerable growth of oysters can take place for no more than two thirds of a year, no growing time should be wasted, *eg*, by exposure at low tides. (*iv*) Oysters in containers are well protected from predators, just as are oysters on trays fixed to the bottom or on trays suspended from rafts. (*v*) German coastal waters offer many more areas suitable for oyster container use than areas sufficiently sheltered for oyster raft culture. (*vi*) Containers which are well submerged in the coastal waters of the North Sea and the Baltic are protected from turbulences during rough weather and from ice, which presents an extreme risk during severe winters. (*vii*) These containers are very useful in areas covered by soft sediments where ground culture of oysters is usually impossible. In the western Baltic, use is made of a former sand dredging pit with a maximum depth of 7 m. The muddy sediments and occasional lack of oxygen in the bottom layers of this pit would result in great losses and slow growth if oysters were to be cultivated on the bottom. (*viii*) With the containers lowered to the bottom, the oysters have good protection from theft.

4 A two-year cycle of oyster production

The present aim is for a two-year cycle of oyster production. A scheme, which serves more or less as a guideline to the fishermen, is shown in Tables I and II.

Hatchery-reared seed *Crassostrea gigas* averaging 0·01 g (5 mm) per individual are stocked on trays in April (month IV) at a density of 5 000/m^2. These trays are suspended from rafts or placed in containers. The density is then gradually reduced through natural mortality, by thinning out (*ie*, filling new trays) and by elimination of slow-growing individuals. The yearlings, of 8·5–10·0 g (4–5 cm), are then transferred to other areas for production of marketable oysters. The trays on which they are stocked with a density of about 600/m^2 from February to April are placed in containers. Stocking density in the second year is again reduced through mortality by thinning out, elimination of slow-growing individuals, and finally by harvesting.

This scheme takes into account a total loss of 50% from seed stage to marketable size. The total loss is quite variable. A total loss in two years of 27% (13% dead or missing oysters plus 14% eliminated because of slow growth) of a small consignment of some hundred seed oysters, which have been checked continuously, is considered an exceptionally good result. A hundred years ago, the traditional German fishery for *Ostrea edulis* yielded 1 market oyster/3·74 m^2/annum. The same sea bottom area used for container culture of *Crassostrea gigas* yields 1 000 market oysters/annum.

TABLE I

HATCHERY-REARED SEED *Crassostrea gigas* ON SMALL-MESH TRAYS, SUSPENDED FROM RAFTS OR PLACED IN CONTAINERS (PHASE I)

Months of the first year	*II*	*IV*	*VI*	*VIII*	*X*	*XII*	*Remarks*
Individual weight (g)	—	0·01	0·5	1·0	5·0	8·0	Reduction in number by: thinning out, mortality and elimination of slow-growing individuals
Number/m^2	—	5 000	2 500	2 000	700	650	

TABLE II

YEARLING *Crassostrea gigas* GROWN ON TRAYS PLACED IN CONTAINERS ON THE GERMAN COASTS (PHASE II)

Months of the second year	*II*	*IV*	*VI*	*VIII*	*X*	*XII*	*Remarks*
Individual weight (g)	8·5	10·0	15·0	30·0	50·0	60·0	Reduction in number by: thinning out, mortality and elimination of slow-growing individuals and harvesting
Number/m^2	625	575	450	250	175	125	

Las Experiencias en el Cultivo de Ostiones del Mangle (*Crassostrea rhizophorae*)

M. Nikolič, A. Bosch, y B. Vázquez

Extracto

Durante un periodo de doce años (1963–74) se efectuaron estudios sobre la biología y ecología de ostiones del mangle así como experimentos de cultivo de esta especie en numerosos lugares alrededor de la Isla de Cuba. El objetivo principal de dichos trabajos fue desarrollar un sistema de cultivo de ostiones del mangle (hasta entonces desconocido) para modernizar los procedimientos inadecuados de la recolección.

Los estudios fueron inicialmente orientados hacia la determinación de las características más importantes de las áreas de cultivo potenciales, estaciones y niveles optimos para la adhesion (fijacion) de las larvas, el crecimiento de ostiones durante el año y su vida, mortalidad natural y el porcentaje de los individuos casualmente desprendidos, consecuentemente perdidos para el cultivador.

De acuerdo con estos conocimientos se ha desarrollado un sistema de cultivo de ostiones del mangle. Las condiciones operativas más importantes del sistema son la correcta ubicación de los colectores y adecuada cosecha. Los rendimientos obtenidos son satisfactorios pero hay todavia algunos problemas, tales como, determinación de la densidad óptima de

individuos por colector, utilización racional de ostiones menores desprendidos casualmente y la interferencia de otros organismos sobre el crecimiento de los ostiones. A estos se les deberá prestar atención durante los experimentos venideros con miras a mejorar el sistema que actualmente se emplea en una granja ostrícola a escala piloto.

Experiments in mangrove oyster culture (*Crassostrea rhizophorae*)

Abstract

During a period of twelve years (1963–74) studies have been carried out on the biology and ecology of mangrove oysters as well as experiments with the culture of this species in many places around the island of Cuba. The main objective of this work was to develop a system of breeding mangrove oysters (until then unknown) in order to modernize the inadequate collection methods.

Studies were originally directed toward determining the most important characteristics of the potential breeding areas, stations and optimum levels for adhesion (fixing) of the larvae, growth of the oysters during the year and during their life, natural mortality, and percentage of individuals accidentally becoming detached, with consequent loss for the breeder.

On the basis of this knowledge a system of mangrove oyster culture has been developed. The most important operative conditions of the system are the correct location of the collectors and adequate harvesting. The yields obtained are satisfactory, but there are still some problems, such as determination of the optimum density of individuals per collector, rational utilization of the smaller oysters which have become accidentally detached and interference of other organisms in the growth of the oysters, to which due attention should be given during future experiments to improve the system which is already being employed on a pilot scale in an oyster farm.

Experiences d'élevage d'huitres de palétuvier (*Crassostrea rhizophorae*)

Résumé

Pendant une période de 12 ans (1963–74), des études ont porté sur la biologie et l'écologie des huîtres de palétuvier et l'on a pratiqué l'élevage expérimental de cette espèce en de nombreux sites dans les parages de l'île de Cuba. Ces travaux avaient pour objectif principal de mettre sur pied un système d'élevage des huîtres de palétuvier (jusqu'alors inconnu) permettant de moderniser les procédés inadéquats de collecte.

Les études ont tout d'abord été orientées vers la détermination des caractéristiques les plus importantes des zones de culture potentielles, des saisons et des fonds qui conviennent le mieux à la fixation des larves, de la croissance des huîtres sur une année et durant tout le cycle biologique, de la mortalité naturelle et du pourcentage d'individus accidentellement décollés, et par conséquent perdus pour l'éleveur.

Compte tenu de ces données, l'on a mis au point un système de culture des huîtres de palétuvier. Les conditions opérationnelles les plus importantes du système sont la localisation correcte des collecteurs et l'emploi de méthodes de récolte adéquates. Les rendements obtenus sont satisfaisants, mais il subsiste un certain nombre de problèmes, comme la détermination de la densité optimale des individus par collecteur, l'utilisation rationnelle des huîtres plus petites accidentellement détachées et l'action d'autres organismes qui nuisent à la croissance des huîtres; on devra prêter attention à ces problèmes lors d'expériences futures pour perfectionner le système déjà utilisé expérimentalement dans une exploitation ostréicole.

1 Introducción

Durante doce años (1963–74) se han efectuado en Cuba estudios biológicos y experimentos en el cultivo de ostiones del mangle (*Crassostrea rhizophorae*). Dicha especie abunda en las costas (estuarios, lagunas, ensenadas, etc.) pobladas por mangle rojo (*Rhizophora mangle*). Los ostiones del mangle se encuentran adheridos, normalmente en camadas, a las raíces terrestres, raíces aéreas zancudas y ramas terminales u otras partes de dicho arbusto pero exclusivamente a los del cinturón cubierto por las mareas (eulitoral).

El principal objetivo de estos estudios fue el de conocer si existe la posibilidad de cultivar dicha especie, nunca lograda con anterioridad, puesto que el Instituto Nacional de la Pesca deseaba modernizar también esta rama de la producción pesquera utilizando las técnicas de cultivo conocidas y eliminando paulatinamente el lento e inadecuado trabajo del 'ostionero' en búsqueda de ostiones en su habitat natural, siempre más alejado y limitado.

Al principio los estudios eran dirigidos hacia las poblaciones de ostiones residentes en áreas naturales. Durante la segunda fase se construyeron instalaciones experimentales de cultivo (en Cabañas, Casilda e Isabela de Sagua) para llegar a practicar en estos momentos ya, el cultivo en pequeña escala comercial (Isabela de Sagua).

Agradecemos a todos los que aportaron con sus esfuerzos al desarrollo de los experimentos descritos en el presente trabajo.

2 Resultados alcanzados durante la fase experimental

2.1 *Las áreas seleccionadas para el cultivo*

Según Nikolić (1970), Nikolić y Alfonso (1971) y Nikolić, Bosch y Alfonso (1976) cada área destinada al cultivo de ostiones del mangle debe reunir las siguientes condiciones ecológicas elementales. La *profundidad* del agua debe estar entre 1 y 2 m (medido con marea baja) para facilitar la construcción de las instalaciones necesarias; la *salinidad* del agua debe ser entre 28 y 36 partes por mil (con pequeños afluentes de agua dulce que no alteran considerablemente o por mucho tiempo estos límites); el *pH* del agua entre 7,9 y 8,1; la concentración del *oxígeno* en el agua entre 2 y 5 mg/l; débiles *corrientes* marinas (unos 30 cm por segundo) además del flujo de las *mareas* las que proporcionarán nuevas masas de agua, facilitarán renovación alimentaria y la difusión de las larvas; adecuada protección (natural o artificial) contra el oleaje excesivo y agua circundante libre de *contaminación*. Las demás condiciones no deben diferir mucho de las encontradas en las áreas naturales.

2.2 *Los métodos utilizados en los experimentos*

Durante los experimentos se construyeron varios tipos de instalaciones descritas por Nikolić y Alfonso (1970 y 1971) y Nikolić, Bosch y Alfonso (1976). Las estacadas en líneas simples, estacadas en líneas dobles y estacadas cuadrangulares dieron resultados similares. Entre los colectores usados (ramas y cujes de mangle rojo *Rhizophora mangle* y de otros arbustos, valvas de ostiones en collares y cestas, tejas de barro y cartones moldeados), fueron precisamente las ramas terminales de mangle rojo las que proporcionaron los mejores resultados. Estos colectores se ataron al principio sobre los arbustos de mangle cercanos. Una de las tareas principales fue establecer el nivel medio del eulitoral (2.3.1) lo que no fue difícil observando la distribución vertical de ostiones naturales y el recorrido diario de las mareas. Los colectores se quedaron así atados (colgados) entre 1 y 3 meses y posteriormente trasladados a las instalaciones preparadas al propósito observando el mismo nivel establecido previamente en el manglar.

2.3 *Algunos datos biológico-pesqueros*

2.3.1 *Reclutamiento.* Los ostiones son de *sexos separados* pero no presentan caracteres sexuales secundarios. El menor macho sexualmente maduro encontrado tenía 14 mm y la menor hembra 19 mm (Nikolić y Soroa Bofill, 1971). La *composición por sexos*, que parece varía durante el año, fue estudiada por distintos autores. Los resultados demostraron que había una relación promedia anual entre los individuos de tamaño comercial de un 32,3% (Nikolić y Soroa Bofill, 1971) y para el total de la población un 45,2% (Bosch y Nikolić, 1975) en favor de los machos. Los individuos a los cuales no se les pudo determinar el sexo oscilaron entre 0,3 y 4,6%. Como un ejemplo, estos porcentajes oscilaban considerablemente durante los años 1969 y 1970. Desde 59,4% en el mes de mayo de 1969 y el 53,4% en septiembre bajó a 24,0% en noviembre, 37,5% en diciembre del mismo año y 29,6% en el mes de marzo del

año siguiente. El porcentaje de los individuos sin poder determinar el sexo bajó desde 9,5% y 6,2% a 5,3% durante estos últimos tres meses. Todo lo dicho hace pensar en la posibilidad de que en ostiones del mangle ocurre un cambio de sexo en determinada época del año y/o de su vida. Nikolić y Soroa Bofill (1971) determinaron (macroscópicamente) cinco *estadios en el desarrollo de la gónada* (0, 1, 2, 3 y 4) siendo los estadios 2 y 3 aptos para desovar o muy próximos a este proceso. Los mismos autores registraron un alto porcentaje de estos dos estadios durante los meses de marzo, abril, agosto, septiembre y octubre en los años de estudios. Bosch y Nikolić (1975) encontraron que el mayor porcentaje (53% y 70%) de estos estadios lo hubo en Casilda entre los meses de noviembre de 1969 y marzo de 1970. El *desove* normalmente ocurre durante todo el año con mayor o menor intensidad pero se distinguen dos períodos de desove más intensivos: marzo–junio y septiembre–noviembre (Nikolić y Soroa Bofill, 1971). Alfonso, Soroa Bofill y Simpson (1973) registraron en Casilda (1970–71) también dos períodos: el primero entre marzo y mayo y el otro desde finales de agosto hasta septiembre. Vázquez, Alfonso y Simpson (1974) encontraron en Casilda (1973–74) 3 períodos (marzo–abril, julio–agosto y noviembre–enero) y en Isabela de Sagua (1973) dos (mayo y julio–agosto). La mayor *abundancia* de las larvas de bivalvos en las muestras del plancton se obtuvieron en Casilda, según Alfonso, Soroa Bofill y Simpson (1973), en abril de 1971. Vázquez, Simpson y Soroa Bofill (1974) registraron el mayor número de larvas de ostiones en Casilda durante los meses de julio (2 088 larvas por m^3 de agua) y diciembre (1 610 larvas). Según los mismos autores hay de 6 a 8 veces más larvas de bivalvos cerca del mangle que en las áreas alejadas unos 150 m. Los más altos valores se encontraron durante la bajamar lo que indica que los ostiones mayormente desovan con la bajada de las mareas. Según Nikolić y Alfonso (1971) la mayor *adhesión ('fijación') de las larvas* occurió en Casilda desde febrero a abril. Alfonso, Soroa Bofill y Simpson (1973) registraron lo mismo en Casilda (1971–72) entre abril y mayo mientras que en Cabañas e Isabela de Sagua (1972) se produjo durante el mes de julio. En el año 1973 (Simpson, Alfonso y Soroa Bofill, 1974) se encontró en Casilda mayor número de ostiones juveniles adheridos durante abril y mayo mientras que en Isabela de Sagua esto ocurrió entre los meses de junio y noviembre. Estudiando tres áreas diferentes (Cabañas, Casilda e Isabela de Sagua) entre los años 1971, 1972 y 1973, Vázquez, Alfonso y Simpson (1974) llegaron a la conclusión de que en estas áreas, aunque no comparables entre sí, había un número de ostiones juveniles adheridos durante los meses de mayo a junio y también en los últimos meses del año. Bosch y Nikolić (1975) encontraron en Casilda el mayor número de reclutas entre los meses de junio y agosto de 1969 así como entre noviembre de 1969 y febrero de 1970.

Todo lo dicho hace pensar que la adhesión de las larvas a los substratos varía algo según los años y ocurre en las áreas situadas en la costa norte algo más tarde que en las de la costa sur, probablemente por la bajada y/o subida posterior de las temperaturas del agua.

La abundancia de ostiones varía también en distintos *niveles y distancias de la costa.* Nikolić (1970) repartió un área natural de Casilda, con amplitud de las mareas aproximadamente de 40 cm, en secciones de 5 cm registrando el número de individuos encontrados por cada sección. De este modo obtuvo que el mayor número de ostiones estaba en las secciones entre 10 y 25 cm de altura (por encontrarse un tiempo adecuado bajo el agua y sin importantes competidores); entre los 25 y 40 cm de altura este número iba bajando considerablemente (por tiempo insuficiente de estancia bajo el agua). Muy pocos individuos había entre 0 y 10 cm de altura (debido a la competencia más fuerte, por el alimento y el espacio, con otros organismos). En el sublitoral (enorme competencia) y supralitoral (alcanzado raras veces por mareas altas) los ostiones eran casuales y escasos. Resultados similares obtuvieron Simpson, Soroa Bofill y Alfonso (1974) así como Vázquez, Alfonso y Simpson (1974). Según estos últimos autores el mayor número de fijaciones (Casilda 69,8% e Isabela de Sagua 90,3%) fue en la superficie del colector que quedaba entre la marea media y bajamar, pero más cercano a bajamar. Los mismos autores afirman que la presencia de ostiones varía también en diferentes sitios (distancia del manglar) lo que depende de muchos factores entre los cuales, según parece, las corrientes son los más importantes.

2.3.2 *El crecimiento.* El crecimiento de ostiones del mangle es relativamente rápido en comparación con otras especies. Sáenz (1965) encontró el crecimiento diario de 0,50 mm en Cabañas y 0,42 mm en Isabela de Sagua para los individuos juveniles (tallas por debajo de la maduración sexual). Nikolić (1969 y 1970) obtuvo en Casilda (1965–66) mediante observación directa los siguientes promedios para el crecimiento diario: hasta la edad de 2 meses 0,52 mm, entre 3 y 5 meses 0,34 mm, entre 6 y 8 meses 0,19 mm; más tarde el crecimiento fue lento y/o casi ninguno. Nikolić y Alfonso (1971) encontraron que los ostiones alcanzaron el tamaño comercial mínimo establecido de 50 mm entre 5 y 7 meses de edad, pero hallaron también a los individuos con tamaños entre 89 mm (7 meses) y 100 mm (9 meses). El individuo de mayor tamaño encontrado, sin conocer su edad, tenía 118 mm. Bosch y Nikolić (1975) efectuaron 3 series de experimentos (áreas naturales, instalaciones ostrícolas sin interferencia del hombre y con eliminación de reclutas). Solamente algunos individuos alcanzaron la talla de 50 mm a los 4 meses de edad, el 25% de ellos llegaron a esa misma talla a los 5 meses y después de 6 meses el 50% de los individuos tenía dicho tamaño. A los 8 meses había entre los del experimento con la eliminación de los reclutas un 82%. Según Nikolić y Alfonso (1968, 1970 y 1971) la determinación del nivel óptimo de crecimiento para los ostiones (en Casilda son 30 cm donde vive la totalidad y 15 cm intermedios donde vive la mayoría de ellos) es de suma importancia para el éxito del cultivo artificial. Simpson, Soroa Bofill y Alfonso (1974) también determinaron el nivel de crecimiento para Casilda (30 cm) e Isabela de Sagua (50 cm). Según estos autores el mayor crecimiento, no rápido pero constante, fue de los ostiones situados en el nivel medio de las mareas y algo menor se registró entre los que se encontraban cerca de dicho nivel. Los ostiones cubiertos constantemente por el mar sobrevivieron los primeros 3 meses de experimentos a pesar del pequeño crecimiento y los que estuvieron casi siempre fuera del agua crecieron algo, pero perecieron también durante el mismo período. El crecimiento fue siempre mayor durante la primavera.

2.3.3 *La mortalidad.* Varios estudios se encaminaron para determinar también la *mortalidad natural* basándose en el porcentaje de ostiones encontrados muertos sobre los substratos en distintos meses. Además se estimó el número de ostiones *desaparecidos* de la población (desprendidos de los substratos). Nikolić (1969) encontró que la mortalidad natural máxima encontrada en Casilda (1965–66) fue: 49,1% entre los ostiones hasta dos meses de edad, 13,2% entre los de cuatro, 21,2% entre los de seis y 16,8% entre los que alcanzaron ocho meses de edad. En una población, el 91,2% de los muertos pertenecía a los tamaños menores de 50 mm. Según Nikolić y Alfonso (1971) la mortalidad natural encontrada fue mayor entre los individuos de tamaños menores y menor entre los que sobrepasaron los 50 mm. Este último dato será casi siempre afectado si no se conoce el porcentaje de ostiones desprendidos. Bosch y Nikolić (1975) registraron que la mortalidad natural (individuos encontrados muertos sobre los colectores) fue mayor (15 a 59%) durante la temporada de sequía (por el cambio de la amplitud de las mareas) y menor (1 a 20%) durante la estación de lluvias de los años 1969 y 1970.

El *desprendimiento* de ostiones más notable (70,2%) ocurrió, según los mismos autores, durante el mes de noviembre del año 1969 (por el peso y el volumen excesivos de ostiones por colector a los 6 meses de edad durante fuertes marejadas).

A pesar de tratarse de animales sésiles es difícil determinar con exactitud la mortalidad total de los ostiones; tampoco se conocen todas sus causas (Nikolić, 1969).

2.3.4 *Los rendimientos.* El rendimiento de los colectores (sostenedores del cultivo) varió según la época de su colocación, tiempo de permanencia en las instalaciones y el área.

Según Jmeliova y Sanz (1969) la biomasa de ostiones en los mangles de la Bahía de Ortigosa era de 1,7 kg por m^2; sin embargo, los autores afirman que en condiciones de cultivo éstos se podrían colectar hasta 35 kg por m^2.

Nikolić y Alfonso (1968) obtuvieron durante la primera cosecha, después de 5 a 6 meses de colocar los colectores, 10 kg de ostiones por cada 3 a 4 colectores (mínimo 2,5 kg de ostiones por colector). Otro dato obtenido para la primera cosecha por los mismos autores (1971) arrojó 1,2 kg por colector en el período desde marzo a septiembre (seis meses) en Casilda. Según Simpson, Alfonso y Soroa Bofill (1974) en Puerto Jobabo, Casilda, cada colector dió 4,5 kg y en Isabela de Sagua solamente 1,0 kg de ostiones durante su tiempo útil de aprovechamiento (8 y 9 meses). Bosch y Nikolić (1975) obtuvieron en instalaciones ostrícolas de Puerto Jobabo, Casilda, un promedio de 5,2 kg de ostiones de tamaño comercial por cada colector en ocho meses de su permanencia en las instalaciones de cultivo (colocados en abril de 1969 y analizados en diciembre del mismo año).

3 Aplicación de los resultados experimentales al cultivo comercial

3.1 *Los procedimientos de cultivo en pequeña escala comercial*

Una vez seleccionada el área es conveniente cubrir todo el perímetro de su costa con una 'cortina' de *colectores* atados a las ramas del arbusto (mangle) a distancias mínimas y a nivel que coincida con el nivel que ocupa la mayoría de los ostiones naturales. Esta labor inicial, que debe repetirse en varias estaciones del año, permitirá localizar lugares y temporadas con fijaciones más abundantes. El número de colectores dependerá de estas informaciones. Los colectores se mantienen en lugares seleccionados durante uno o dos meses y se aprovecha este tiempo para la construcción de instalaciones sencillas. También las instalaciones hay que construirlas en lugares, que de acuerdo con las experiencias, ofrezcan mejores condiciones (Nikolić, Bosch y Alfonso, 1976).

A las cuatro semanas se realiza la primera *limpieza* de los colectores, liberándolos de los competidores y observando la aparición y progreso en el crecimiento de los reclutas 'fijaciones'. La segunda limpieza tiene lugar cuatro semanas después cuando se determina el número de fijaciones y también se decide la fecha de *traslado* a las instalaciones preparadas para el cultivo (Fig. 1). Si las condiciones así lo permiten es conveniente establecer dos áreas no muy lejanas; una para 'capturar las fijaciones' y la otra donde se practicará el cultivo.



Fig 1. Vista parcial de un criadero de ostiones del mangle en pequeña escala comercial

Al colocar los colectores en las instalaciones hay que tener especial cuidado de atarlos al nivel *medio de las mareas* en el área y acorde a la temporada puesto que las amplitudes de las mareas suben en septiembre y octubre, bajan durante enero, febrero y marzo y se mantienen en un nivel intermedio en mayo y junio aproximadamente. Deben hacerse *ajustes* adecuados durante las épocas del año que siguen a las temporadas de colocación. Sencillas técnicas para efectuar dichos ajustes han sido descritas por Nikolić, Bosch y Alfonso (1976). Se debe *inspeccionar* periódicamente el estado de las instalaciones observando también el desarrollo de ostiones en cultivo, usando técnicas de muestreo preparadas a tal propósito. Cuando los colectores de una cohorte cumplen su quinto mes de exposición, es el tiempo oportuno para realizar la primera *cosecha*. Esta se efectúa principalmente sobre las ramificaciones terminales inferiores del colector donde fácilmente puede ocurrir el desprendimiento por el peso excesivo de individuos crecidos. Sucesivas cosechas se cumplen en intervalos mensuales. Los cultivadores desprenden a los ostiones individualmente y/o en racimos a mano, utilizando los guantes de lona fina, aprovechando las mareas bajas. La recolecta se puede hacer también durante las mareas altas extrayendo a cada uno de los colectores fuera del agua, colgándolos en las instalaciones a un nivel más alto.

Todos estos trabajos se efectúan en pequeños botes llamados 'pandera' o 'bongo' (Fig. 2) en los cuales los cultivadores pueden moverse entre las instalaciones con facilidad.



Fig 2. Las instalaciones ostrícolas (estacadas en línea doble con colectores suspendidos) atendidas por cultivadores

3.2 *Los rendimientos obtenidos*

El método desarrollado (Nikolić, Bosch y Alfonso, 1976) ha proporcionado hasta la fecha los siguientes rendimientos:

Tipo de instalación	*Mínimo kg*	*Promedio kg*	*Máximo kg*
1—colector/tiempo útil (8–9 meses)	1,2	5,2	—
2—colector/año	—	7,7	10,0
3—sección/año			
estacadas en línea (simple)	30	—	64
estacadas en línea (doble)	70	—	128
estacadas cuadrangulares	700	—	1 200
camadas	18	—	24

Se estima que cada *cultivador* debe atender, bajo las condiciones de cultivo comercial, por lo menos 7 500 colectores de los cuales en la producción constante estarían unos 3 500 de ellos, produciendo aproximadamente 26,2 toneladas de ostiones anualmente. Para eso se necesita solamente un área entre 600 y 700 m^2.

Con la introducción del cultivo de esta especie se pretende ofrecer al cultivador el campo de producción (granjas ostrícolas) cercano a su residencia. De este modo él puede producir más de lo que encuentra durante las búsquedas en los viajes a lo largo de la costa a través del año.

3.3 *Las dificultades y las perspectivas*

Una de las dificultades afrontadas durante las labores de cultivo fue la *densidad* excesiva de ostiones obtenida por cada colector. Es por eso que la tarea inmediata de los investigadores será determinar el número óptimo de individuos que se puede cultivar por cada colector sin que éstos se afecten mutuamente. Algunos (Jmeliova y Sanz, 1969) han dirigido sus esfuerzos en calcular la biomasa de ostiones sobre una superficie natural determinada y a estimar las mismas bajo las condiciones artificiales de cultivo (2.3.4). Tales informaciones pueden proporcionar orientaciones útiles pero desde el punto de vista práctico es bueno desarrollar el cultivo en cada nueva área, en forma progresiva y mantener un control estadístico basado en el registro de la producción (rendimientos de los colectores, producción por área, *etc*) y mediante muestreo sistemático. Durante los estudios preliminares sobre la densidad y la selección (Bosch y Nikolić, 1975) se observó el crecimiento de un número limitado de ostiones juveniles en colectores (183) eliminando consecuentemente a todos los reclutas y a otros organismos aparecidos posteriormente. Ocho meses más tarde hubo un 82% de individuos mayores de talla comercial por cada tal colector (comparado con 46% solamente en áreas naturales y 52% en colectores sin interferencia del hombre). Los resultados preliminares indican que estudios similares pueden proporcionar las informaciones útiles sobre el número óptimo de ostiones que puede sostener cada colector.

Otra tarea inmediata sería los estudios sobre el mantenimiento de individuos no comercializables desprendidos

casualmente durante las cosechas para llevarlos hasta la talla comercial. Algunos estudios realizados con anterioridad (Nikolić, 1969; Nikolić y Alfonso, 1971). no dieron resultados satisfactorios.

La mayoría de las *áreas* estudiadas reunen las características necesarias para el cultivo de ostiones del mangle y para desarrollar también otros cultivos como camarones (*Penaeus duorarum* y *Penaeus schmitti*), peces herbívoros (*Mugil* var. sp.) etc.

4 Conclusiones

Los estudios biológicos y los experimentos de cultivo demostraron que es posible cultivar a los ostiones del mangle por el método desarrollado con este propósito.

Las condiciones ecológicas de innumerables áreas (ensenadas, bocas de estuarios, etc.) favorecen dicho cultivo pero difieren algo entre la costa sur y la costa norte de Cuba.

La adhesión de las larvas (aparición de los reclutas) sobre los substratos artificiales (colectores) disponibles es casi continua destacándose dos épocas de mayor intensidad.

El crecimiento de los individuos adheridos es relativamente rápido alcanzando un 50% de ellos el tamaño comercial establecido (50 mm) entre los 5 y 6 meses de edad.

La mortalidad natural es mayor entre los individuos de menores tamaños (hasta 50 mm) y menor entre los mayores. Esta también varía por temporadas; es menor durante la estación de verano (lluvias) y mayor durante el invierno (sequías y mareas bajas). Si no se realizan las cosechas en el momento oportuno y con la periodicidad indicada se puede producir desprendimiento elevado de individuos (principalmente con tallas mayores) los cuales desaparecen de la población y de este modo afectan la producción.

Los rendimientos de los colectores (durante tiempo útil y por año), de las secciones y del cultivador (por año) son aceptables y la primera cosecha debía realizarse entre los 5 y 6 meses después de la colocación de los colectores. Las cosechas parciales hay que efectuarlas todos los meses subsiguientes.

Para obtener mejores resultados de los alcanzados hasta el presente debe perfeccionarse aún más el método de cultivo aplicado a través de los estudios sobre la densidad óptima de individuos por cada colector, sobre la utilización racional de ostiones desprendidos casualmente y sobre la interferencia de diversos organismos asociados (competidores, enemigos, etc.) con los ostiones cultivados.

Las áreas dedicadas al cultivo de ostiones del mangle deberían estudiarse también con miras a utilizarlas, en un futuro cercano, como áreas para practicar el policultivo.

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Tropical Mangrove Oyster Culture: Problems and Prospects

A. B. Kamara, K. B. McNeil, D. B. Quayle

Abstract

Unlike oysters in temperate zones, it is only recently that the potential for cultivating mangrove oysters in many tropical countries has been realized as a local source of protein and as a possible export commodity.

Mangrove oysters in their natural environment have typically stunted populations, growing to a maximum size of 5 cm. The stress of exposure to long periods of heat is thought to contribute to the stunting process. Seed for mangrove oyster culture is readily available on mangrove roots (virtually a self-disintegrating cultch), but intensive cutting of mangrove roots should be controlled to prevent elimination of this valuable resource. Modifications of the basic oyster culturing techniques of 'off-bottom' rearing appear to be most suited for mangrove oysters. The two most important problems in their culture include fouling and low salinities during the rainy season.

Other factors which should be considered in developing mangrove oyster culture include: land ownership, leasing and tenure, pollution, navigable waters regulations, market research, processing plant design, and training oyster culturists.

Investigation of culture techniques applicable to *Crassostrea tulipa, C. brazilliana* and *C. belcherii* in Sierra Leone, southern Brazil and

Sabah, Malaysia, respectively, have given promising results. Best growth was achieved in Sabah, Malaysia with *C. belcherii* through a combination of rack and raft (with trays) culture techniques. Seed collected on asbestos strips and reared on racks and rafts reached a length of 14 cm (meat weight 14–21 g) after 18 months.

It is considered that culture of mangrove oysters offers excellent potential for further development, and to a large extent the prospects may be limited by the problems of transfer of culture technology for entrepreneural or artisanal participation, and the provision of investment financing to the latter group.

L'élevage de l'huître de palétuvier dans la zone tropicale: Problèmes et perspectives

Résumé

A la différence de l'ostréiculture en zone tempérée, ce n'est que récemment que l'on a pleinement mesuré, dans nombre de pays tropicaux, le potentiel de l'élevage des huîtres de palétuvier comme source locale de protéines, voire comme produit d'exportation.

L'huître de palétuvier dans son habitat naturel forme des populations qui se caractérisent par leur croissance arrêtée, puisque cette huître n'excède pas une taille maximale de 5 cm. L'on estime que l'exposition à de longues périodes de chaleur contribue au processus de rabougrissement. L'on trouve facilement des géniteurs pour l'ostréiculture sur les racines des palétuviers (qui constituent pratiquement des collecteurs de naissain à autodésintégration), mais l'on devrait s'opposer au découpage excessif des racines de palétuviers pour prévenir la disparition de cette utile ressource. Les techniques traditionnelles d'élevage de l'huître sur support avec quelques modifications semblent convenir particulièrement aux huîtres de palétuviers. Les deux problèmes les plus importants auxquels se heurte cet élevage sont les salissures et la faible salinité pendant la saison des pluies.

Parmi divers facteurs qu'il faut envisager en mettant sur pied un tel élevage figurent: le régime de propriété, de location et de tenure des terres; la pollution; les règlements relatifs aux eaux navigables: les études de marché; la conception des usines de traitement et la formation des éleveurs.

Les recherches sur les techniques d'élevage applicables à *Crassostrea tulipa, C. braziliana* et *C. belcherii* en Sierra Leone, au Brésil méridional et au Sabah (Malaisie) ont donné des résultats prometteurs. On a obtenu les meilleurs au Sabah (Malaisie) avec *C. belcherii*, en combinant des techniques d'élevage sur pieux et sur radeaux (et claies). Des géniteurs recueillis sur des bandes d'amiante et élevés sur pieux et sur radeaux ont atteint une longueur de 14 cm (poids de chair 14–21 g), au bout de 18 mois.

L'on estime que la culture des huîtres de palétuvier offre un potentiel de développement excellent, mais que ses perspectives risquent d'être limitées par les problèmes du transfert technologique tant pour les entrepreneurs que pour les exploitations artisanales, ainsi que par les difficultés du financement des investissements nécessaires à ce dernier groupe.

Cultivo de ostra de manglar en zonas tropicales: Problemas y perspectivas

Extracto

A diferencia de lo que ha sucedido con las ostras de zonas templadas, sólo recientemente se ha caído en la cuenta de las posibilidades que ofrece, en muchos países tropicales, el cultivo de ostras de manglar para producir proteínas y disponer de un producto de exportación.

La ostra de manglar, en su ambiente natural, es característicamente pequeña, alcanzando una talla máxima de 5 cm. Se cree que a ello contribuye la exposición a largos períodos de calor. La semilla para el cultivo de ostra de manglar puede recogerse fácilmente en las raíces de mangle (que constituye prácticamente un soporte que se desintegra por sí solo), pero es preciso controlar la corta de raíces de mangle para no acabar con este valioso recurso. La técnica más adecuada para la ostra de manglar es una modificación de la técnica básica de cultivo sin contacto con el fondo. Los dos problemas más importantes en el cultivo de estos moluscos son incrustación y la salinidad durante la estación de las lluvias.

Otros factores que hay que tener en cuenta al considerar el desarrollo del cultivo de la ostra de manglar son: propiedad, arrendamiento y tenencia del suelo; contaminación; regulación de las aguas navegables; estudios de mercados; preparación de plantas de elaboración, y capacitación de ostricultores.

El estudio de las técnicas de cultivo de *Crassostrea tulipa, C. braziliana* y *C. belcherii* en Sierra Leona, el sur de Brasil y Sabah (Malasia), respectivamente, ha dado resultados prometedores. El mejor crecimiento se ha logrado en Sabah (Malasia) con *C. belcherii*, combinando las técnicas de cultivo en bastidores y en balsas (con bandejas). Las larvas de ostra recogidas en láminas de asbesto y criadas en bastidores y balsas alcanzaron luego de 18 meses una longitud de 14 cm (peso de la carne 14–21 g).

Se estima que el cultivo de ostra de manglar ofrece excelentes posibilidades de desarrollo pero las perspectivas podrían verse parcialmente limitadas por los problemas que plantean la transferencia de tecnología de cultivo para la participación empresarial o artesanal y la aportación de capital para inversiones al último grupo.

1 Introduction

The great oyster industries of the world have been developed in the temperate zones by entrepreneurs, large and small, because of the availability of ready markets. This was probably due to the high esteem in which oysters have always been held by all economic levels of the population.

In the tropics, although oysters are as widely distributed as in the temperate zones, they have not been accorded the same regard and have remained merely as one of a number of naturally occurring foods of relatively low value. Moreover, temperate zone oysters were easily cultivated because of the occurrence of natural beds of fairly large oysters and the existence of substrates where oysters could be relaid. This is seldom the case with mangrove oysters.

There have been sporadic attempts to cultivate mangrove oysters but the investigations were seldom pursued beyond preliminary experiments. Recently, there has developed in many tropical countries an awareness of the potential of the oyster as a local source of protein and as a possible export commodity. There have been numerous inquiries to organizations concerned with resource development and, as a partial result, there has been the opportunity to examine the mangrove oyster as a culturable organism in seven tropical countries on four continents. This paper is a review of the conclusions derived from these experiences and of oyster culture projects in progress in Sierra Leone, West Africa; in Sabah, Malaysia and in Brazil, South America.

2 The mangrove environment

Mangrove trees, mainly *Rhizophora* and *Avicennia* but also a number of other genera, are common along the shores and estuaries on the continental masses between the two tropics, and in some cases extend both north and south of these boundaries. The water temperatures in this region are consistently high, generally between 20 and 30°C. Salinity, however, may vary considerably, from zero during the annual rains to 40 ppt in the dry season. Mangrove trees are characterized by the formation of numerous aerial roots in addition to the main stem, so the silt-laden currents, either tidal or river, are interrupted by these barriers and silt is deposited. Thus, an important feature of the mangrove environment is the extremely soft muddy substrate, rich in organic matter at the mud-water interface, but anaerobic beneath. Thus, it is nearly impossible for oysters to settle or survive on this type of substrate. Mangrove areas are also normally well protected from excessive wave action, which is also conducive to the siltation process. Because of the high organic content of the mangrove area waters, they are deemed to be highly productive. However, owing to the restrictive shore environment, the invertebrate biota is not extensive and consists mainly of oysters attached to the mangrove roots, gastropod molluscs and crustaceans.

3 Mangrove oysters

Many genera of oysters occur in mangrove areas. *Crassostrea rhizophora* occurs in the Caribbean and West Indies, succeeding *C. virginica* where euryhaline and hyperhaline salinities occur due to evaporation in high temperatures. In general, *Crassostrea* or *Saccostrea* appear to occur in the true mangrove environment although the latter may occur in the tropical rocky intertidal along with *Striostrea*. These are very broad generalizations and exceptions may occur

according to the particular environment and geographic area.

The mangrove *Crassostrea* occurs typically on the aerial roots of the mangrove trees or bushes. The tree roots remain relatively free of silt because of their vertical position, current action and wave lapping, and they develop a firm, hard surface owing to the relatively long periods out of water. Therefore, they form ideal setting surfaces for oyster larvae, being the only sites in the mangrove environment where the tidal range is usually not more than 3 m. Oyster larvae no doubt settle on the roots from the highest tidal level to the mud line but mortality occurs down to about the 1 m level, and survival increases from there toward the mud line. Oyster growth rates follow the same pattern, being least at higher levels and increasing toward the mud line, and growth is a function of the period of submergence. This period, even at the low level of the mud line is insufficient for *Crassostrea* to realize its full growth potential. Except in special circumstances, and these do occur occasionally, the mangrove oyster is typically stunted with a maximum size of about 5 cm. Doubtless the stress of heat through many hours of exposure each day contributes to the stunting process. In some areas at least, the normally intertidal mangrove oyster can survive and grow when moved from the mangrove root to continuous submergence.

4 Seed availability

A consistent supply of seed is a basic requirement for successful oyster culture and is often a problem in temperate zones, hence the development of oyster hatcheries. In most mangrove oyster areas, however, there is usually an over-abundance of seed, and their availability is not a limiting factor. There are two possible techniques for collecting seed for culture purposes. One is to expose cultch to collect seed by traditional techniques, and the other is to utilize the smaller oysters (which in reality are a form of seed) on the adventitious mangrove roots. In the latter, the roots are simply cut from the tree with the attached oysters. However, it has been found that when these aerial roots with the attached oysters are immersed continuously in salt water the oysters drop off owing to decomposition and sloughing of the bark of the root. Thus, the mangrove root is virtually a self-disintegrating oyster cultch, a feature which has been widely but unsuccessfully sought in temperate zone oyster culture.

Retention of the oysters after sloughing to permit continued growth may be accomplished with trays if these are economically feasible. Alternatively, it may be possible to enclose the mangrove root in a webbing or net tube, such as is used in one form of mussel culture.

Use of the mangrove seed, which are by this time 2–3 cm in diameter, provides a growth gain of several months over collected seed and the equivalent of nearly a full year's growth in the seven or eight months of the dry season. This presumes the mortality of the mangrove oysters is not excessive during the rainy season.

If mangrove roots are to be used for oyster culture the question of conservation must be considered and some form of controlled cutting may be desirable, according to the local situation. Most mangrove estuaries have many miles of shore with oyster-covered mangrove roots, which constitute a potentially valuable resource if properly used.

A serious difficulty in developing a culture system for mangrove oysters is the lack or shortage of materials readily available to temperate zone culturists. This is particularly so if the development is to be on an artisanal level. Experience has shown that bamboo may be used for cultch, trays, racks, and floats. The new synthetic twines are relatively inexpensive and long lasting.

5 Culture methods

There are numerous variations of the relatively few basic methods of oyster culture. Nearly all of them have been in existence for a very long time and most of the innovations relate only to new types of material. The most basic is bottom culture, as this seems to be the normal habitat of most oyster species, and it is the type that, in the past, has produced the greatest volume of oysters. The other basic type has been termed 'off-bottom' rearing, where the greatest strides in oyster culture have been made in recent years although the principle dates back to Roman times. Oysters may be held off the bottom by suspending them from rafts or racks on strings, panels or in trays. Possibly the most recent innovation is their suspension in mesh tubes, such as are used in one form of mussel culture. Oysters may also be held off bottom on single vertical stakes. Except for the mesh tube system, all of these forms of culture have been well documented in literature.

Decision on the most suitable system of culture for the mangrove oyster may be assisted by the use of a simple form of analysis, with the various culture types being assessed against a list of factors known to be significant in their success or failure. For instance, trays or strings suspended from rafts may be compared either quantitatively or qualitatively against such factors as growth rate, condition factor, fouling, predation, capital cost, and working cost. To assess the suitability of a given area for the various types of culture, comparisons may be made on such factors as: temperature, salinity, depth, substrate, tidal level, tidal range, wave action, predation, and navigation area available. Such tabulations provide a visual image and form a basis for discussion.

Such evaluations for most mangrove situations show that rack or raft culture are likely to be most effective.

The decision relative to the use of strings or trays is based on the local economic situation relating to such factors as labour, material costs, and market value of the oyster.

6 Culture problems

It is obvious that any culture technique to induce mangrove oysters to grow faster and larger means longer or total periods of immersion, which generally involves some form of hanging culture, such as suspending strings or trays from submerged racks or rafts. This introduces two factors which have, in the past, been the main obstacles to advancement in the utilization of mangrove oysters. One is fouling, which may either inhibit entirely or reduce the growth rate of the oyster. The other is the low salinity mortalities during the rainy season, which in some instances may be enough to decimate the intertidal stocks of mangrove oysters, as in the Jaguaribe River in north-eastern Brazil.

In some circumstances it is possible to accept the fouling that occurs. Alternative solutions may be related to timing of the initial immersion to evade at least some of the fouling

organisms. This presumes knowledge of the main species, their breeding cycles and growth rates. Chemical control by pre-dipping cultch in certain pesticides may be used to inhibit settling of a specific organism, but not of oysters. This, however, is not a satisfactory solution. A further method of control is by dessication where oysters are removed from the water for periods long enough to kill at least the soft-bodied organisms, such as tunicates, polychaetes and hydroids, and yet not harm the oyster. Alternatively, the material may be dipped briefly in fresh water or a concentrated saline solution. Most of these methods are fairly costly in terms of labour and equipment.

Another method that should be investigated involves taking advantage of the euryhalinity of most species of *Crassostrea* and the stenohalinity of most fouling organisms. Mangrove oysters occur in estuaries and it may be possible to locate areas, usually distant from the ocean, where the salinity is high enough (10–15 ppt) to permit oyster growth, yet low enough to inhibit settlement of most fouling organisms and possibly oyster larvae as well. On the west coast of North America (USA and Canada) the introduced Japanese oyster (*Crassostrea gigas*) flourishes in temperatures and salinities where the species does not reproduce. This permits complete separation of the year-classes during culture. This is a critical difference when compared with tropical oyster habitats.

Regarding the possible effects of salinity reduction during the rainy season, there are two main solutions. The first, and likely to be of most practical use, is the design of the culture schedule to encompass a single dry season. Breeding appears to take place during most of the year and, in some cases, into the beginning or at the end of the rainy season. Proper timing of the collection of seed may permit taking full advantage of the total duration of the dry season which may be seven or eight months. Growth is so rapid at the prevailing high temperatures in mangrove areas, that oysters of a size which may be marketed after one season (*ie*, eight months) are obtained. This schedule obviates the risk of mortality from reduced salinity and in a single season the fouling problem will be less than in an extended period. Further, optimum use is made of the equipment whether it be raft, rack or tray, which are the large investment items.

The alternative is to lower the oysters below the halocline if one exists and if there is sufficient depth of water. Depending on the geography of the area, it may be possible to move rafts or accumulated seed to areas of higher salinity during the rains.

7 Other considerations in development of mangrove oyster culture

As well as the biological aspects in the culture of oysters, such as breeding and growth rate, there are administrative problems to be considered.

7.1 *Land ownership, leasing and tenure*

To grow oysters it is necessary to have property rights to land, either intertidal or subtidal, and to the cultured oysters themselves. This may be in the form of outright ownership or on a lease basis. If the latter, then length and security of tenure is involved. Leases for a reasonable length of time, at least 10 years, must be secured before capital is likely to be invested. There should also be reasonable expectations that the lease will be renewable. If the situation requires leases, then lease fees and taxes must be at a level that the developing industry can accommodate.

7.2 *Pollution*

It is the established practice in countries or states with an oyster industry to carry out sanitary and pollution surveys of an area before permission to cultivate oysters is granted. This is to protect the health of the public, as filter-feeding shellfish, such as the oysters, have the ability to concentrate pathogenic bacteria and virus particles as well as heavy metals, such as copper and zinc. These surveys include oceanographic studies for current configurations, the location of present and potential pollution sources, and the bacteriological quality of the growing waters and of the shellfish. Even if all of these factors are satisfactory, regular surveillance is continued.

For import of filter-feeding shellfish, most countries require reciprocal agreements on sanitary control. This comes about only after lengthy negotiations have shown that adequately safe sanitary controls are applied.

The mangrove environment is most frequently associated with estuaries. These are favoured locations for cities and villages, which tend to furnish industrial and sewage pollution sources that are most difficult to eliminate or control. Pure water sites for natural purification or artificial purification facilities for oysters using chlorine, ozone or ultra-violet light must be considered in the early stages of the development of an oyster industry in such situations. Illness, such as typhoid or infectious hepatitis, traced to oysters, can destroy an oyster market for many years.

7.3 *Navigable water regulations*

Since oyster culture in most mangrove situations requires either racks or floating structures, these may constitute navigational hazards. There are doubtless navigable water regulations, so permission will be needed to place such structures in these waters.

Another consideration is the historic rights of local fishermen to navigable waters. Unless co-operation and/or involvement is obtained at an early stage, it has been found most difficult to maintain even experimental material in such areas.

7.4 *Market research*

The specific type of culture methods employed will, in part, be determined by the kind and form of oyster product that is to be marketed. For example, information, such as size and shape requirements, is necessary if a raw (half-shell) oyster is to be produced. The cultural requirements can be quite different if a processed (shucked) oyster for soups, canning, freezing, smoking or for the fresh market is envisaged.

The location and possible extent of these markets is necessary information in respect to storage and transportation facilities. Oysters spoil very quickly at high temperatures so cooling and refrigeration will be the most important consideration in the tropical climate, unless a dried and sealed product is produced.

7.5 *Processing requirements*

Doubtless there are local regulations governing the design and construction of food processing plants. These will have to be investigated and considered relative to the special requirements for processing oysters.

Whatever processing methods are to be used will depend largely on the outcome of the market studies. Oyster processing techniques have been well worked out and the main problem is to adapt them to artisanal use where necessary.

7.6 *Training oyster culturists*

A problem in beginning a new industry is the supply of trained people. Workmen of potential foreman calibre should be associated with the oyster work from its inception so they may take charge of field work and train others as needed. This phase cannot be over-emphasized.

8 Recent results of mangrove oyster culture in selected countries

8.1 *Sierra Leone*

In the Sierra Leone oyster culture project a variety of culture techniques were used in the Freetown estuary with *Crassostrea tulipa* (Kamara and McNeil, 1975). The conclusion is that a string system either from rafts or racks produces the most satisfactory results. Collected seed grown on rafts for the seven to eight months of the dry season have produced oysters quite acceptable to the market. With a mean length (height) of 7 cm and some as large as 10 cm, this oyster is four times the volume of the mangrove oysters now being marketed. Seed is readily available over most of the year. The condition factor has so far shown only mediocre values with no apparent seasonal trend. This may be typical of this mangrove oyster, or it may be a reflection of the size and age as it is with most *Crassostrea* in temperate waters.

The market requirements in Sierra Leone are not being met with the wild mangrove oyster harvest and the potential is believed to be considerable.

8.2 *Brazil*

In southern Brazil in the Cananeia area south of São Paulo, a culture technique has been developed for the mangrove oyster *Crassostrea brasiliana* (Quayle, 1973; Wakmatsu, 1973). In this area the water temperature varies between 20 and 30°C and the salinity between about 10 and 30 ppt. Breeding occurs over most of the year with a main peak from February to May. Shells, bamboo, asbestos or roofing tiles are suggested as cultch materials.

Bottom, raft and rack culture have been used. Bottom culture here requires about 18 months to harvest oysters about 6 cm in length and 30 months for an 8 cm oyster.

In north-eastern Brazil, floods are of sufficient frequency to be inimical to oyster culture possibilities in a number of otherwise suitable estuaries.

8.3 *Sabah, Malaysia*

In Sabah, a working system of oyster culture has been recently developed for the mangrove oyster (*Crassostrea belcherii*) of that area (Chin and Lim, 1975). The basic culture technique is a combination of rack and raft with trays. The water temperature in the Tawau area ranges between 27 and 31°C while the salinity varies from 22 to 28 ppt. Breeding appears to occur thoughout the year but with two peaks, one in spring and one in winter. Forecasting is based on the correlation between spawning and the occurrence of sudden and heavy rains, usually accompanied by a water temperature drop. Various types of cultch have been tested; strips of corrugated roofing asbestos proved to be the most useful. Fouling of collectors by barnacles was avoided by timing the exposure of cultch and placing it at the correct tidal level.

The seed is collected on the asbestos strips held in trays on racks and retained there for about four months after which they are removed to higher intertidal racks for hardening. After two months on these racks the individual seed, now 3–5 cm in length, are removed from the cultch surface and grown in trays suspended from rafts. After one year on the trays, 80–90% of the oysters had reached a length of 14 cm with a range in meat weight of 14–21 g. The condition factor ranges between 115 and 135 points on the standard 50 to 150 condition scale for oysters.

The productivity of this system in Sabah in the Tawau area is estimated to be about 18 000 kg/ha/year.

9 Prospects

The mangrove oyster has two important attributes that provide it with an extraordinary potential. These are its fecundity and an environment that permits a rapid growth rate. The seed supply in most areas is virtually unlimited and data from widely separated studies indicate that a marketable oyster may be produced in a growing season of 18 months or less.

Of equal significance is the vast stock of oysters present on countless mangrove roots which have little value *in situ* or as a crop because of small size. With the right technology they may be utilized and the costly seed collection step removed from the culture procedure by a natural, automatically-suspended cultch.

The potential is there. Some of the culture problems have been explained and some solutions or partial solutions advanced as demonstrated by the projects described. Others will be forthcoming as projects already under way continue and others are developed. To a large extent the prospects may be limited by the problems of transfer of culture technology for entrepreneural or artisanal participation, and the provision of investment financing to the latter group.

10 Acknowledgements

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Oyster Mortalities and their Control

C. J. Sindermann

Abstract
Major oyster mortalities are a matter of record in most of the world's principal production areas, where they have often caused significant population reductions. Some of these major mortalities have been ascribed to epizootics caused by infectious agents; many, however, remain of 'unknown origin' despite intensive scientific investigation. European, Japanese, and North American oyster populations have been affected in this century by catastrophic mass mortalities, in some cases bringing the oyster industry to a standstill for a number of years.

In addition to the widespread catastrophic mortalities, many other mass deaths of a more localized nature occur in oyster populations and there are also continuing background mortalities which may at times reach levels of concern to the shellfish industry. Reduction of the impact of mortalities on production usually takes the form of adapting culture practices to take advantage of salinity, temperature, or other limitations on the activities of the causative factor or factors.

La mortalité des huîtres et les mesures de contrôle
Résumé
La plupart des principales zones de production du monde ont gardé trace des mortalités massives d'huîtres, qui ont fréquemment entraîné des réductions sensibles de la population. Certaines de ces grandes mortalités ont été attribuées à des épizooties provoquées par des agents infectieux tandis que nombre d'entre elles restent d' 'origine inconnue' en dépit de recherches scientifiques approfondies. Les populations d'huîtres européennes, japonaises et nord-américaines ont été atteintes au cours de ce siècle par des mortalités catastrophiques, qui dans certains cas ont conduit à la stagnation de l'industrie ostréicole pendant un certain nombre d'années.

Outre les mortalités catastrophiques très répandues, de nombreuses autres morts massives plus localisées ont atteint des populations d'huîtres; en outre, des mortalités prolongées atteignent parfois des niveaux qui préoccupent l'industrie des crustacés et mollusques. Réduire l'incidence des mortalités sur la production consiste généralement à adapter des pratiques culturales aux conditions de salinité, de température et à d'autres limitations de l'activité du ou des facteurs pathogènes.

Mortandades de ostras y lucha contra las mismas
Extracto
Importantes mortandades de ostras se han registrado en la mayoría de las principales zonas productoras del mundo, que a menudo han determinado reducciones notables de la población. Algunas de esas mortandades se han atribuido a epizootias producidas por agentes infecciosos, pero muchas de ellas siguen siendo 'de origen desconocido', a pesar de las intensas investigaciones científicas realizadas. Las poblaciones de ostras de Europa, Japón y América del Norte han sufrido durante este siglo mortandades catastróficas, que en algunos casos han reducido a la inactividad a la industria de la ostra durante varios años.

Además de esas mortandades catastróficas, se producen en las poblaciones de ostras otras muchas muertes masivas de carácter más circunscrito y hay también una mortalidad continua 'de base' que, en algunas épocas alcanza índices que llegan a inquietar a la industria marisquera. Normalmente se intenta reducir las repercusiones de esa mortalidad en la producción adaptando los sistemas de cultivo para aprovechar la salinidad o la temperatura o limitando de otras formas la actividad del factor o factores que la producen.

1 Introduction

Most of the great fisheries of the world have experienced fluctuations in supply. Causes of such fluctuations have been much discussed but rarely determined precisely. Among the factors implicated in reductions in abundance are: overfishing, inadequate management, failure of spawning, inadequate food supply, disease, sudden and drastic changes in the environment, and a host of other factors. Among marine populations such as oysters, which occur in shallow coastal waters, mass mortalities have occurred repeatedly in this century, and have resulted in significant reductions in production—sometimes with long-term effects. Identification of precise causes has proved to be very difficult; only a few mass mortalities have been definitely associated with specific pathogens, predators, or other environmental factors.

It is the purpose of this paper to review briefly the world experience with mass mortalities of oysters in the 20th century, with particular attention to causes, effects, and control measures—if any. Oyster mortalities have been and are a matter of great concern to a number of nations which harvest wild stock or, more frequently, cultivate oysters in coastal and estuarine waters. Within the past decade alone, mass mortalities have affected production of oysters in Japan, France, the United States and the United Kingdom. Earlier mortalities also affected production in these and other countries as well. Mortalities in some producing areas have exceeded 95% of existing populations in a single growing season; in other areas mortalities have been less, but often repeated for several years before abating. Effects, in terms of lost production, have been and can be determined accurately.

It might be well at this point to discuss a few generalizations about mortalities and their causes. It should be stated at the outset that mass mortalities are merely an exaggerated form of natural mortality, usually distinguished by being of rapid onset, and affecting a large proportion of the population over an extensive geographic area. Many mass mortalities of oysters undoubtedly result from interactions of environmental and biological factors; only a few have been clearly associated with a single overriding causal factor; and of these few, disease has usually been the identifiable cause.

'Disease' in its broadest sense can be defined as any departure from normal structure or function of a living organism. Origins may be infectious or non-infectious. Included in the *non-infectious* category are such phenomena as: environmentally induced skeletal anomalies, genetic abnormalities, physiological malfunctions due to chemical environmental factors, metabolic disorders resulting from nutritional deficiencies and many forms of neoplasms.

Disfunction and death due to the activity of infectious agents constitute the narrower, but often predominant, concept of disease. *Infectious diseases*—caused by viruses, bacteria, fungi, protozoa and others—are usually prime suspects in searches for causes of mortalities, sometimes to the exclusion of other possible causes.

In many instances of mass mortalities, it is probably the combination of an infectious agent and environmental stress that eventually kills animals on a large scale.

Although mass mortalities of oysters are natural phenomena, man has done a number of things to increase the likelihood of their occurrence. He has crowded individuals into dense populations, often under marginal environmental conditions; he has transferred stocks promiscuously, leading to introductions of predators and diseases not previously known in the receiving area (Alderman, 1974); and he has modified the estuarine oyster production areas by dredging, dam construction, the use of fertilizers, and the release of chemical contaminants.

In considering the information about mass mortalities of oysters we should not overlook the continuing background mortalities that are less spectacular but not less significant in determining population size. These mortalities are represented by the slow, continuous extraction of individuals from the population by deaths due to inadequate food, salinity extremes, predation, temperature extremes, siltation, low oxygen levels, crowding effects, *etc.* Actually, the dividing line between 'background' mortality and 'mass'

mortality is hard to define and is only a matter of degree. As a very rough criterion, maximum background mortality in many oyster populations can be considered to be 10–15% in a single year (exclusive of larval and spat mortality); anything above that figure should probably be termed a mass mortality. This estimate is of course variable from area to area; some oyster growers become alarmed if annual mortalities exceed 5% while others in different geographic areas tolerate annual mortalities approaching 50%. Other definitions of mass mortality exist. Koganezawa (1975) defines it as the death annually of 50–60% of the oysters—which he considers the boundary of existence of Japanese commercial oyster culture.

It should also be recognized that localized mass mortalities, involving relatively restricted geographic areas, can and do occur, and can produce significant localized effects. Predators such as starfish, crabs, polyclad flatworms or oyster drills can increase in abundance explosively, and kill large numbers of oysters—particularly spat and seed. Changes in the physical environment, such as severe flooding of rivers, with consequent reduction of salinities over oyster beds near river mouths, can cause localized, often complete, mortalities (Nikolić, 1964). Such local mass mortalities undoubtedly occur by the hundred as compared to one of the major widespread mortalities discussed in this paper.

So, with the qualifications mentioned above, it seems that natural mortality of oysters can be considered (somewhat artificially, perhaps) in three aspects: (*i*) background mortality, a continuous, often unnoticed, but very significant reduction in numbers of individuals at any stage of the life history; (*ii*) localized mass mortalities, affecting restricted geographic areas and killing up to 100% of the populations in those areas; and (*iii*) widespread and extensive mass mortalities, affecting large geographic areas and reducing oyster production in these areas significantly. This paper, confined largely to the third type of mortality, is an attempt to distill the often frustrating research—over a 75-year time span—designed to understand the nature and causes of catastrophic mortalities, and to find control measures.

Some earlier efforts have been made to summarize information about oyster mortalities (Gross and Smyth, 1946; Mackin, 1961; Sindermann, 1968, 1970; Sprague, 1971). Because of the world-wide economic importance of oysters, and because they have long been cultivated in shallow estuarine and coastal waters, it is only natural that mortalities, when they occur, would be observed and examined. This paper is an attempt to review the published results of the examinations. Mortalities will be considered chronologically, by major geographic areas. Table I lists those to be considered.

2 Oyster mortalities in Europe

The history of oyster mortalities in Europe is long and at times confusing. Species of consequence there are the flat oyster, *Ostrea edulis*, and the Portuguese oyster, *Crassostrea angulata*. Recently the Pacific oyster *Crassostrea gigas* has been introduced on a large scale on the French coast.

Among the oldest recorded mass mortalities of oysters was that which occurred in the Arcachon basin, France, in 1877 (Hornell, 1910; Dollfus, 1921; Orton, 1937). The cause was not determined, but characteristics of dying oysters led to the application of the name 'maladie du pied' to the disease condition. The disease is localized in the shell under the attachment of the adductor muscle, where it causes roughening and blistering of the shell and degeneration of adjacent muscle tissue. The muscle may become detached as irregular cysts are formed. Giard (1894) described a possible etiological agent as a bacterium, *Myotomus ostrearum*, but subsequent studies have cast doubt on this conclusion. It seems now that 'maladie du pied' is a form of fungus-induced shell disease, which will be considered later.

The next major European oyster mortalities in chronological sequence began in 1919. Catastrophic mortalities of

TABLE I
MAJOR OYSTER MORTALITIES DURING THE PAST CENTURY

Year (s) of mortality[1]	*Species affected*	*Affected area*	*Probable cause*
1877–	*Ostrea edulis*	France	'Maladie du pied' (probably the fungus *Ostracoblabe implexa*)
1915–	*Crassostrea gigas*	Japan (Kanasawa Bay)	Unknown
1915–1957	*C. virginica*	Canada (Gulf of St. Lawrence)	'Malpeque Bay disease', cause unknown
1919–1923	*O. edulis*	Europe	Unknown
1924–	*Crassostrea commercialis*	Australia (NSW)	Unknown
1927–1937	*C. gigas*	Japan (Miura Peninsula)	Unknown
1930–	*O. edulis* *Crassostrea angulata*	Europe	'shell disease' caused by the fungus *Ostracoblabe implexa*
1945–1955	*C. gigas*	Japan (Hiroshima Bay)	Unknown (bacterial infection suggested)
1949–	*C. virginica*	US (Gulf of Mexico)	Fungus *Labyrinthomyxa marina*
1959–	*C. virginica*	US (Atlantic Coast)	Haplosporidans, *Minchinia nelsoni, M. costalis*
1961–	*C. gigas*	Japan (Matsushima Bay)	Unknown (physiological and environmental factors may be involved)
1963–1969	*C. gigas*	US (Pacific Coast)	Unknown
1967–1973	*O. edulis* and (to a lesser extent) *C. angulata*	Europe	'digestive gland disease' cause unknown
1967–1973	*C. angulata* and (to a lesser extent) *O. edulis and C. gigas*	Europe	'gill disease' probably the *Labyrinthomyxal*-like protistan named *Thanatostrea polymorpha*
1972–	*C. commercialis*	Australia (Queensland)	Haplosporidan (not further described)

[1] A dash (–) after the date of mortality indicates that the exact year when mortalities ceased is not adequately reported in the literature availab[le]. In some instances, mortalities did not cease, but merely receded into background levels

Ostrea edulis occurred in western Europe. Deaths began in 1919 in Mar Piccolo, near Taranto, Italy (Cerruti, 1941) and soon after were reported in England and other European countries, where they persisted until 1923. Orton (1924, 1924a), who carried out exhaustive and painstaking investigations during the period, suspected but was unable to demonstrate a bacterial pathogen. Although no infectious agent could be directly associated with the mortalities, disease signs such as mantle retraction, pale digestive glands, muscle degeneration, gut inflammation, and shell and mantle pustules were seen. Ulcerations and pustules on the body and mantle, and shell pustules containing dead or moribund leukocytes were observed in oysters from England and the Netherlands during the mortality (Orton, 1937). These signs are quite likely associated with a disease process. In addition to the exhaustive studies of Orton, Eyre (1923, 1924) isolated a fungus, *Cladothrix dichotoma*, and nine species of bacteria from sick and healthy oysters, but expressed doubt that any were true pathogens.

Korringa (1952) has given an excellent historical account of these mortalities of 1919–1923. Cultured oyster beds in France, England, Denmark, Germany, and the Netherlands were affected almost simultaneously, beginning in late 1919, peaking in 1920, and abating in 1921–1923. In Ireland, the peak was in 1921. Many natural beds were also destroyed. A few isolated populations (Helgoland and Brittany) were not affected until several years later. Mortalities did not occur in Portuguese oysters, *Crassostrea angulata*. Although environmental factors such as poor food supply and low temperatures were claimed to be causes of the catastrophic mortalities by a few authors (Gaarder and Alvsaker, 1951; Spärck, 1950), the available evidence strongly indicates an infectious disease (Cole, 1951; Fischer, 1951; Korringa, 1952).

Beginning in 1930, mortalities affected *Ostrea edulis* stocks in the Netherlands. Deaths were attributed to 'shell disease' (Korringa, 1947; 1951, 1951a) thought to be caused by a fungus. The disease condition had been known in the Netherlands since 1902, but began an explosive increase in the Oosterschelde in 1930, following implementation of a programme for widespread use of cockle shells as spat collectors.

The disease was characterized by formation of green or brown pustules on the inner shell surfaces. Activity of the fungus varied directly with temperature. Thin parts of oyster shells were perforated by the disease agent, which proliferated after reaching the interior surfaces. The fungus was identified as a species of *Monilia* by Voisin (1931), who found the infection in 40% of oysters imported into France from the Netherlands in 1931. Cole (1950) and Cole and Waugh (1956) reported infections in the European oyster from Brittany, and in Portuguese oysters, *Crassostrea angulata*, grown in England. Infections were common in beds where old shells were abundant. Cole and Hancock (1956) found the disease in almost all beds of native European oysters in England, and described two distinct forms: the typical one, characterized by greenish rubbery warts and knobs on the inside of the shell, particularly in the region of the muscle attachment; and an atypical form in which young oysters had thickened shells with numerous white patches but had no deformation of the muscle attachment area. The shells of affected oysters may be distorted, the condition index is reduced, and the adductor muscle may become detached.

A subsequent severe outbreak of shell disease with high mortalities occurred in the summer of 1947, and the disease is now known thoughout western Europe in *Ostrea edulis* and *Crassostrea angulata*. Recent work by Alderman and Jones (1967, 1971) identified the causative organism as the phycomycete *Ostracoblabe implexa*, and considered shell disease and 'maladie du pied' (discussed earlier) to be identical.

Beginning in 1967, new oyster mortalities began to affect production in western Europe. Some of the mortalities have been attributed to so-called 'gill disease', which was first reported in Portuguese oysters, *Crassostrea angulata*, from the French coast by Marteil (1968). It was almost simultaneously reported from Portugal (Vilela, 1968) and from the United Kingdom (Howell, Key and Shotton, 1968). Alderman (1969) and Alderman and Gras (1969) reported heavy mortalities (in some instances over 90%) of *C. angulata* imported to England from Portugal in 1969. Mortalities were severe in 1968 and 1969 in Portuguese beds (Vilela and Sampayo, 1969). Gross indications of abnormality were similar to those seen in 1967 and 1968 in France, where mortalities were also severe (reaching 80% in the Marennes-Oleron region). Affected oysters had thin, yellowish meats, with damage to gills and palps, and to a lesser extent the adductor muscle and mantle, in the form of yellow-green pustules which increased in size and developed into extensive brownish areas of necrosis. The disease condition was described in 'active' and 'remission' stages (the remission stage apparently lacks the yellow staining and brownish necrotic areas).

The precise etiology of gill disease is still somewhat in doubt. Besse and Poirier (1968) felt that the disease was due to erosion of the gills by *Trichodina*, while Arvy and Franc (1968), Gras (1969), and Comps (1969, 1969a, 1969b) found cells in gills and palps of infected oysters in French waters that they felt were similar to life history stages of *Labyrinthomyxa marina* (the organism responsible for oyster mortalities in the Gulf of Mexico and southern Atlantic coast of the United States). Franc and Arvy (1969) then described as *Thanatostrea polymorpha* n. sp. the *Labyrinthomyxa*-like organism thought responsible for gill disease on the coast of France.

Similar stages have been observed in many of the affected oysters in England, and have been isolated in culture (Alderman and Gras, 1969). Specimens of *O. edulis* have been found in France, Portugal and the Netherlands with some of the same disease signs (remission stage), and a *Labyrinthomyxa*-like organism was isolated from a French sample by Alderman (1969). Comps (1969a) found gill disease in *Crassostrea gigas* imported as seed from Japan, Korea, and British Columbia after one year's residence in French waters. Recently, Cousserans *et al* (1974) cultured heart tissue from *C. gigas* sampled on the Atlantic coast of France and found numerous isolates to be parasitized by an organism with stages similar to *Labyrinthomyxa marina*. Despite what seemed like a consensus in the published literature favouring a *Labyrinthomyxa*-like pathogen, recent unpublished observations by several European workers suggest that the disease may be of viral etiology.

Alderman (1971) reported a decrease in mortalities due to gill disease in England in 1970. Mortalities continued high through 1973 in the Arcachon and Gironde production areas of France, reducing stocks drastically. Only the replacement of *C. angulata* by *C. gigas* in the Arcachon

basin has enabled continued production there, according to Deltreil (1973). A proposed method to reduce effects of gill disease was proposed by Deltreil (1969, 1969a, 1971). Oysters not sold but remaining on beds after three years were heavily infected and could constitute a reservoir of infection. Deltreil suggested the destruction of all oysters unsold at four years, and preferably at three years.

A second disease, of uncertain etiology, called 'Aber disease' or preferably 'digestive gland disease' has recently been reported as a cause of mortalities in *Ostrea edulis* on the French (Brittany) coast (Comps, 1970; Herrbach, 1971; Bonami *et al*, 1971). Mortalities began in 1967, continued to spread until 1972, and began regressing in 1973 (Grizel and Tige, 1973; Tige and Morel, 1974). Characteristic disease signs include poor condition index, yellowing of the digestive gland, glycogen loss, and tissue necrosis. One histological feature of significance is the presence in the digestive gland tubule epithelium (and occasionally in gills and palps) of spherical bodies containing several types of inclusions. A preliminary paper (Grizel *et al*, 1974) concluded that the parasite was unlike any oyster pathogen whose life cycle had been described. A subsequent paper by Grizel *et al* (1974a) named the parasite *Marteilia refringens*, without establishing its taxonomic position. Perkins (1976) employed ultrastructural studies to demonstrate affinities of the organism to the protozoan class Haplosporea. Rosenfield (1976) also concluded independently (based on examination of the photomicrographs of Bonami *et al*, 1971) that the parasite observed in digestive gland disease of *O. edulis* was probably a haplosporidan.

The digestive gland disease was considered by French workers to be specific for *Ostrea edulis*, but recently very similar histological observations were made in *Crassostrea angulata* populations undergoing massive mortalities on the southern coast of Spain (Gutierrez and Pascual, 1975). Mortalities of up to 90% occurred in certain growing areas in 1973 and 1974.

Although difficult to sort out specifically, it seems that during the past eight years in Europe, two disease conditions have affected oysters and produced severe mortalities: gill disease, principally in *C. angulata* and to a lesser extent in *O. edulis* and *C. gigas*; and so-called digestive gland disease, of uncertain etiology, in *O. edulis*, and to a lesser extent in *C. angulata*.

Examining the impressive array of European oyster mortalities over the years, and seeing the evidence (however inconclusive) that activities of infectious agents were probably involved in most of them, it is easy to conclude, as Mackin (1961) did earlier, that 'of all causes of mortality, disease ranks first', that 'at the present time all oyster-producing bays are endemic areas for one or more diseases', and that 'bivalve molluscs . . . are regularly parasitized by a unique group of low fungi' (the *Labyrinthomyxa*-like organisms).

3 Oyster mortalities in Asia

The Japanese literature contains numerous historical accounts of mass oyster mortalities of unknown etiology dating back to 1915. Although disease was sometimes suspected, specific pathogens were usually not identified. Takeuchi, Takemoto and Matsubara (1960) mentioned large-scale deaths of oysters in Kanasawa Bay, beginning in 1915 and continuing for a number of years. Over 80% of the oysters in that bay died annually. Ogasawara *et al* (1962) reported similar mass mortalities on the Miura peninsula, beginning in 1927 and continuing for 10 years. Oyster farms all along the coast of the peninsula lost from 50 to 80% of their crop annually.

More recently, large-scale mortalities of 2-year-old Pacific oysters, *Crassostrea gigas*, occurred in Hiroshima Bay and adjacent localities, beginning in 1945 (Fujita *et al*, 1953, 1955). A 10 year study (Takeuchi, 1963; Takeuchi *et al*, 1955, 1956, 1957; Takeuchi, Takemoto and Matsubara, 1960) provided somewhat inconclusive evidence that a bacterial pathogen was responsible for the mortalities. Takeuchi, Takemoto and Matsubara (1960) implicated a gram-negative, motile, 1–3μ bacillus, probably an *Achromobacter*, although the evidence presented was incomplete. Experimental infections were achieved with cultured bacteria, but the organisms could be isolated from healthy as well as sick oysters, and also from sea water. Moribund oysters were characterized by diffuse cell infiltration, massive increase in bacterial numbers, and tissue necrosis. These mortalities should probably be categorized as 'of unknown origin.'

Probably the best documented, most studied, but least understood oyster mortalities in Japan began in Matsushima Bay and adjacent waters of Miyagi Prefecture about 1961 (Fig. 1). A series of papers published in the Bulletin of the Tohoku Regional Fisheries Research Laboratory in 1965 (Imai *et al*, 1965; Kan-no *et al*, 1965; Mori *et al*, 1965, 1965a; Numachi *et al*, 1965; Tamate *et al*, 1965) described studies of mass mortalities of oysters that occurred annually in late summer. Environmental, physiological, and pathological factors were examined. Pathological changes were observed, and the cause of mortalities was believed, inconclusively, to be related to metabolic disturbances associated with spawning. An elaborate physiological explanation for mortalities of oysters in hanging culture in Matsushima Bay was proposed by Mori, Tamate and Imai (1966); Mori *et al*, (1965, 1965a) and Mori (in press). The hypothesis is based on overmaturation of the gonad under the influence of high temperatures and eutrophication of growing areas, disturbance of lipid and steroid metabolism, extreme decline in physiological activity, and death.

Mortalities exceeded 60% per year in certain areas of the Bay during the period 1961–1965, and were selective in that other bivalves did not die. Mature oysters in apparently good condition (by gross examination) died. A gram-positive bacterium was found in multiple abscesses in up to 20% of certain samples (Numachi *et al*, 1965), but a causal relationship with mortalities was not thought to exist. Later studies by the Oxford (Maryland) Laboratory of the US Bureau of Commerical Fisheries (now the National Marine Fisheries Service) suggested that the disease condition is the same as that called 'focal necrosis' in adult Pacific oysters from Washington, and in Japanese seed oysters imported into Washington. The pathogen warrants further observation, because the abscesses may represent only the chronic stage of infection in more resistant hosts; the acute disease may be significant in mortality.

The work of Japanese scientists involved with the Matsushima Bay mortalities has been of particular conceptual importance in that it de-emphasized infectious disease and emphasized other, and in some instances new, possible



Fig 1. Oysters from hanging culture in Matsushima Bay, with empty shells indicating recent mortalities

causes of mortalities—particularly the physiological stress hypothesis described above.

Koganezawa (1975) in an informative summary, states that mass deaths of oysters have occurred annually since 1961 in Matsushima Bay and since 1969 in other important oyster culture areas, particularly but not exclusively on the Pacific Ocean coast of Japan and the Inland Sea. Mortality rates were estimated at 40–60% annually. Koganezawa further points out the striking resemblance of earlier mass mortalities in Hiroshima and more recent ones in Matsushima Bay. Characteristics in common are that mortalities: occur during and immediately following the spawning season, are greater in larger, faster-growing oysters, begin when water temperatures reach 21°C, and are more severe when temperatures are high. He points out that most of the major Japanese oyster production is in areas of advancing eutrophication, and subscribes to the hypothesis of Mori (described above) which attributes mortalities to gross metabolic disturbance resulting from heavy and rapid gonad formation and massive spawning during times of high water temperatures in eutrophic bays. Infectious agents are not considered by Koganezawa to be primary causes of mass mortalities in Japan.

Japanese oyster growers are apparently adopting practices which prevent heavy gonad formation and massive spawning, in an attempt to reduce mortalities. Koganezawa describes two methods: (*i*) the use of hardened seed oysters (exposed to winter air temperatures during part of the tidal cycle); and (*ii*) placement of oysters in poor nutritional areas during the gonad maturation period, and their removal to nutritionally rich areas for fattening in fall and winter. Both methods prevent or postpone gonad formation; it will be interesting to see if they also prevent mortalities.

Koganezawa makes the additional observation that the development of intensive hanging culture methods for oysters in Japan has been accompanied by increasing mass mortalities. Emphasis on early fattening and harvesting and higher production in restricted areas may have contributed to the mortality problem. A paper from the Republic of Korea (Chun, 1970) where intensive hanging culture was introduced in 1963 supports a possible association of this type of culture with mortalities. Comparing mortality rates of oysters grown by the traditional bamboo stake method with those grown in hanging culture, Chun found significantly higher mortalities in the latter (a peak of 37% in hanging culture in 1969 opposed to only 12% in bamboo stake culture).

4 Oyster mortalities in North America

Oysters of commercial importance in North America include: the American oyster, *Crassostrea virginica*, grown on the Atlantic and Gulf of Mexico coasts; the Pacific oyster, *Crassostrea gigas*, introduced in the 1920's on the Pacific coast; and the Olympia oyster, *Ostrea lurida*, native to the Pacific northwest. Trial introductions of the European oyster, *Ostrea edulis* have been made on both the Atlantic and Pacific coasts, but these have not yet achieved general commercial significance.

Oyster production in North America is still largely from natural beds, even though some rudimentary culture practices are carried on, and even though some commercial shellfish hatcheries exist. Many of these natural beds have been affected by mass mortalities—some of extended duration, with long-term impacts on production.

Mortalities with a history of long and frustrating scientific study were first observed in 1915 in *Crassostrea virginica* from Prince Edward Island, Canada, in the Gulf of Saint Lawrence (Needler and Logie, 1947). In the period from 1915 to 1939, the disease called Malpeque Bay Disease, spread around the Island and destroyed most of the oyster stocks, some of which required 20 years to return to previous levels of abundance (Logie, 1956). The most obvious signs of distress were extreme thinness of meats, yellow-green pustules on the body surface, stunting of shell growth, and failure to spawn. About 95% of all oysters in an affected area were killed within three years of the first deaths. During the outbreak period, oysters apparently developed resistance to the causative organism, whose identity remains undetermined. Recovery of a devastated stock by natural reproduction of resistant stock to a point where it could support a fishery took from 10 to 15 years (Logie, 1956). During this period, severe selection pressure was demonstrated by high but declining mortalities of spat.

Beginning in 1955, mortalities (probably due to the same disease) began in waters of the adjacent mainland of New Brunswick across the Northumberland Strait from Prince Edward Island. Oyster populations along the entire northern coasts of New Brunswick and Nova Scotia were decimated within the next five years, but mass transfer of disease-resistant oysters from Prince Edward Island waters, beginning in 1957 and continuing until 1962, hastened the

recovery of the fishery (Logie, 1958; Logie, Drinnan and Henderson, 1960; Drinnan and England, 1965).

The great oyster mortalities of the Gulf of Saint Lawrence have waned; recovery of stocks has been aided by transplantation, but control of the causative agent was achieved only by natural forces. If the mortalities were due to an infectious agent, and if that agent is still present (as it seems to be) in resistant stocks, then it is hard to understand why the identification of the disease organism has proved to be so difficult, in view of the intensive (if somewhat sporadic) investigations which were carried out. Today, sixty years after mortalities began, the cause of the mortalities remains a mystery.

While the early oyster mortalities in Canada caused by 'Malpeque Bay Disease' have left scientists with a sense of frustration, investigations of recurring mortalities of *Crassostrea virginica* in the Gulf of Mexico beginning in the late 1940's have proved more definitive. Mackin, Owen and Collier (1950) recognized and described a primitive fungus, *Dermocystidium marinum* (now called *Labyrinthomyxa marina*) as the etiological agent. Exerting its effects in higher salinities and temperatures among dense aggregations of oysters, the pathogen has been reported to cause annual mortalities in excess of 50% (Ray, 1954, Ray and Chandler, 1955; Mackin, 1962). It has been identified in oysters throughout the Gulf of Mexico and northward along the Atlantic Coast as far as Connecticut. Although prevalence of the fungus may at times reach epizootic proportions in particular areas, its most significant effect is probably that of continuing attrition year after year during periods of high seawater temperatures. Effects of the disease on commercial beds are now controlled to some extent by planting and harvesting at prescribed times of the year and by planting oysters thinly on beds.

Early discovery of a useful diagnostic technique, based on a fluid-thioglycollate medium fortified with antibiotic, by Ray (1952, 1966a) enabled rapid determination of infection levels and distribution of the pathogen. *Labyrinthomyxa marina* is common in most high salinity waters of the southern United States. Ray (1966) surveyed the occurrence of the fungus in the Gulf of Mexico in 1961 and 1962, and found infections in 35 of 39 oyster samples, with prevalences as high as 100%. Hoese (1964) was able to find *Dermocystidium marinum* in the digestive tracts and faeces of fish, oyster drills, and crabs that had fed on dying and dead infected oysters. He speculated that transmission of the fungus might be furthered by scavengers, and that scavengers may release the parasite from host tissue.

Pathological changes in infected oysters were described by Mackin (1951). Invasion takes place through the gut epithelium and possibly through the mantle. The epithelium is destroyed; the parasite lyses the basement membrane and is distributed by the blood to all parts of the body. All tissues are invaded and damaged, and multiple abscesses are formed. Normal gonad development is inhibited, infected oysters become severely emaciated (Ray, Mackin and Boswell, 1953; Ray 1954a), and growth is retarded (Menzel and Hopkins, 1955).

Temperature is important in the epizootiology of *Labyrinthomyxa* disease (Hewatt and Andrews, 1956). Infections and associated mortalities rise during the warm months and decline during colder periods. Mortalities decline in winter, probably because of reduced parasite metabolism rather than elimination of the organism. Failure to find *L. marina* consistently north of Chesapeake Bay suggests that prolonged low temperature may be a significant limiting factor. Andrews (1965) found that the organism proliferates readily only at temperatures above 25°C, and overwinters as sub-patent infections. Infections and resulting mortalities are reduced in salinities below 15‰. Ray (1954a) showed that low salinity retarded development of terminal infections in laboratory populations. Ray and Chandler (1955) suggested that excessively high salinities may also be unfavourable for *Labyrinthomyxa*. Mackin (1956) found a positive correlation between high salinity and high incidence of the fungus, but observed in experimental studies that the salinity tolerance range was wide. Dilution of infective elements by inflow of fresh water was suggested as an important limiting factor and a possible control measure.

The continuing role of *Labyrinthomyxa marina* as a cause of mortalities has been investigated. A detailed study of the pathogen in Florida waters (Quick and Mackin, 1971) indicated that 'the normal annual mortality from *L. marina* parasitism is about 50% of the adult oyster population.' Other studies have disclosed high prevalences of the pathogen in Texas, Mississippi, and Louisiana waters. Oyster culture schedules and planting densities have been adapted to reduce the impact of the disease. Methods used include: (*i*) low density planting (since transmission of the pathogen is direct), (*ii*) early harvest at minimal commercial sizes, (*iii*) planting of large seed oysters in high salinities late in the growing season, and (*iv*) utilization of low salinity growing areas.

Major mortalities, with consequent severe depression of the oyster fishery, occurred in Delaware and Chesapeake Bays on the United States east coast, beginning in the late 1950's. A haplosporidan parasite with distinctive characteristics, *Minchinia nelsoni* (Fig. 2), has been associated with the mortalities. Extensive mortalities and drastic decline of the oyster fishery began in Delaware Bay about 1957, and in lower Chesapeake Bay in 1959 (Haskin, 1961; Mackin, 1960; Engle and Rosenfield, 1963; Andrews, 1964). In each affected area, mortalities exceeded 95% for several years. Because of the severe impact of the *M. nelsoni* epizootic on *Crassostrea virginica* stocks of the Middle Atlantic states, a number of university, state, and federal research groups have participated in scientific studies since the late 1950's, and significant papers have been published.

Farley (1965, 1968), after completing a 5-year histopathological study of Chesapeake Bay oysters, categorized natural infections according to extent of invasion and nature of host response. He found that initial infections occurred in epithelia of gills and palps. The pathogen spread into adjacent connective tissue, provoking infiltration of hyaline haemocytes. In intermediate infections the haplosporidan plasmodia invaded connective tissue adjacent to the digestive tract and gonad, and advanced infections were recognized by generalized invasion and infiltration of connective tissue by hyaline haemocytes. Terminal infections were characterized histologically by pyknosis of nuclei and tissue necrosis even before gross signs of death were apparent. Farley also recognized a stage of the disease termed 'remission,' identified by diminished intensity of infection and cell infiltration, localization of parasites near external epithelia, increased pigment cell formation, diapedesis, deposition of necrotic tissue and moribund parasites



Fig 2. Minchinia spores in tissues of *Crassostrea virginica*

against the shell, and conchiolinous encapsulation. Death from *M. nelsoni* infection was attributed to combined action of seasonal, environmental or physiological stresses on oysters weakened by effects of the disease.

As an example of the effects of *Minchinia nelsoni* on the United States oyster fishery, landings in New Jersey waters of Delaware Bay in the late 1940's and early 1950's had fluctuated around 6 million pounds (2 724 metric tons) of shucked meats. Disease decimated the stocks beginning in the mid-1950's. Landings fell precipitously to a low of 165,000 pounds, (75 metric tons) in 1960, and have not recovered significantly (Fig. 3). Recent statistics disclose landings still under 1 million pounds (454 metric tons). Comparable effects have been felt in the high salinity waters of lower Chesapeake Bay, another major oyster producing area. The grim story of the effects of 'Delaware Bay Disease' in Chesapeake Bay has been summarized by Andrews and Wood (1967). '. . . 1960 was the year of reckoning for the industry. Late winter losses were followed by near decimation in early summer of plantings made before June 1959. In 1960 the last commercial plantings were made in lower Chesapeake Bay and oysters were decimated in a vast area. By June 1961, all plantings worth salvaging had been marketed, regardless of age. Millions of dollars worth of oysters were lost in 1960 . . .'.

One alleviating influence seems to be salinity. *M. nelsoni* occurs in waters whose salinity consistently exceeds 15‰; during the years 1963–1965 with low rainfall along the Atlantic coast, the pathogen invaded areas of middle Chesapeake Bay formerly free of the disease (Rosenfield and Sindermann, 1966). Probably the clearest observational evidence for the decisive role of salinity in the epizootiology of the disease was presented by Andrews (1964). Simultaneous examinations of salinity regimes, disease prevalence, and mortalities in the James River seed beds of Virginia disclosed that infections disappeared from areas of marginal disease occurrence during low seasonal salinities and during several years of rainfall. The importation of the infective agents from high salinity areas of the lower estuary of the James River was postulated to explain the persistence of the disease in marginal salinity zones.

Temperature is also an important factor in the epizootiology of *M. nelsoni*. Andrews (1966) found that in Virginia infections persisted through the winter; death rates decreased with decreasing temperature in autumn but rose again in February and March. Infection of new hosts and mortality peaks occurred primarily during the warm season.

Whether the disease was newly introduced into waters of the Middle Atlantic states or was enzootic in *Crassostrea virginica* populations of the area, remains unresolved. Circumstantial evidence favours the view that *M. nelsoni* was present years before the epizootic (Andrews and Wood, 1967; Andrews, 1968) and that some change in the pathogen or the host population permitted an outbreak to occur. It is perhaps pertinent that similar organisms have been reported as rare parasites of Pacific oysters (*C. gigas*) in Washington, Republic of Korea and Taiwan Province of China (Pereyra, 1964; Sindermann and Rosenfield, 1967).

At the beginning of the major east coast oyster mortalities caused by *Minchinia nelsoni* in the late 1950's, a second haplosporidan, *Minchinia costalis*, was identified as the cause of simultaneous, but geographically restricted mortalities. The organism was found in seaside bays of Maryland and Virginia, along the lower eastern shore of Virginia, and in Delaware Bay (Andrews, Wood and Hoese,1962; Wood and Andrews, 1962; Sprague, 1963; Haskin, Stauber and Mackin, 1966; Couch, 1967). First recognized in moribund and dead oysters from Hog Island Bay, Virginia, by Wood and Andrews (1962), *M. costalis* was held responsible, on the basis of epizootiological evidence, for sharp peaks of mortality in May and June. Striking characteristics of the disease are the sudden onset of mortalities in May, and the abrupt termination of

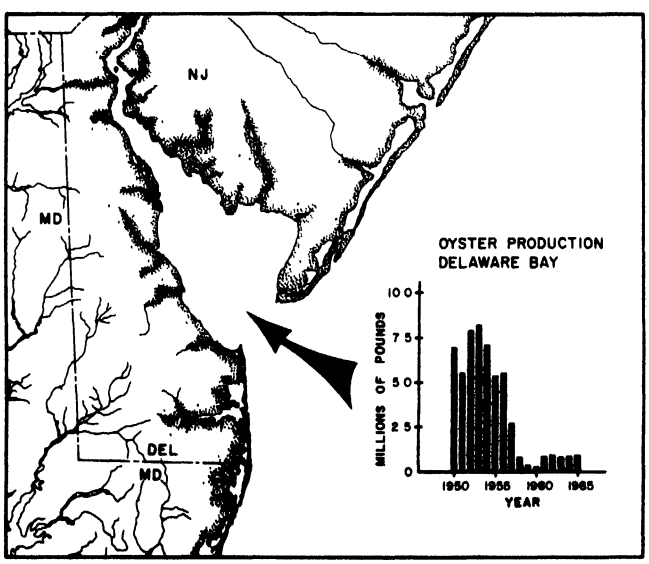


Fig 3. Oyster production in Delaware Bay as affected by *Minchinia nelsoni* epizootic (one million pounds = 454 metric tons)

mortalities about mid-June. The pathogen and mortalities caused by it continue to characterize Maryland and Virginia seaside oyster populations (Couch, 1967; Couch and Rosenfield, 1968).

While mortalities of *Crassostrea virginica* were occurring on the United States Atlantic coast in the late 1950's and the 1960's, similar events were taking place in *Crassostrea gigas* populations on the United States Pacific coast. *C. gigas* at that time was largely imported as seed from Japan and planted in waters of the west coast states of Washington, Oregon, and California. Mortalities were most serious in the two principal west coast growing areas, Puget Sound in Washington, and Humboldt Bay in California. Oysters in their second year after introduction were most commonly killed, and deaths were most often noted at the heads of bays, although occurrences were irregular. Unlike the east coast mortalities, no clear association has been made of specific pathogens with mortalities of *C. gigas* on the Pacific coast of the United States, and it is quite possible that other environmental factors were operative in the mortality areas.

Glude (1975) has published an excellent account of the west coast oyster mortalities, and of the attempts to understand them. Losses in principal growing areas reached 35–58% annually during the 1960's. Oysters died during the second summer following planting; most seriously involved were fast-growing individuals near the heads of eutrophic bays and estuaries in Puget Sound and in much of Humboldt Bay. Glude emphasized the striking similarities between mortalities in Matsushima Bay, Japan, and those in Puget Sound. In both places, as he points out: (*i*) fast-growing oysters died, (*ii*) affected oysters were characterized by rapid over-maturation of gonads, (*iii*) mortality occurred during the summer spawning period, and (*iv*) no specific pathogen could be associated with the mortalities, despite indications of degenerative necrosis of the digestive diverticulum.

In an attempt to understand the causes of the west coast mortalities, a large federally-funded co-operative investigation was carried on from 1966 to 1972. This resulted in an unparallelled description of the pattern of oyster mortalities, related environmental events, and histopathological observations (see section 7). One of Glude's conclusions is that 'The failure of pathological investigations to find a causative organism tends to strengthen the physiological stress theory' (discussed earlier in this paper as Mori's hypothesis to account for Matsushima Bay mortalities). The termination of federal funding in 1972, with consequent reduction in research effort, coincided with a decreasing trend in mortalities observed during 1972 and 1973 (Glude, 1975). This agrees generally with the finding of Sindermann (1975) that, with localized exceptions, west coast mortalities have subsided since about 1970.

5 Oyster mortalities in Australia

Reports of oyster mortalities in Australia extend back to 1890 when Whitelegge (1890) published a report on 'worm disease' caused by *Polydora* (Fig. 4) in New South Wales. He considered the disease (with limited evidence) as a cause of extensive mortalities which eventually brought about the development of intertidal culture methods in New South Wales.

Commercial oyster production in Australia, according to Wolf (1967) is restricted largely to New South Wales, and to the Sydney rock oyster, *Crassostrea commercialis*. Throughout much of the 20th century, an important factor limiting production has been the so-called 'winter mortality.' First described in scientific literature by Roughley (1926), the mortalities had characteristics very similar to those seen in European *Ostrea edulis* during the extensive



Fig 4. Polydora infestation of oysters

mortalities of 1919–1923. Roughley described mass deaths of oysters in the Georges River, NSW in 1924 and 1925. Disease signs, in the form of abscesses and ulcerations were observed, and a bacterial pathogen was suspected but not demonstrated. Winter environmental stress was also implicated, since rock oysters are grown intertidally.

Wolf (1967) has reviewed the history of 'winter mortality'. He feels that the cause is still essentially unknown, but salinity may be a factor, since high mortality occurs in years of low autumn rainfall. Bacterial infections may be involved, possibly aggravated by winter stress. Wolf reports that annual and areal effects may vary, but severe outbreaks of 'winter mortality' can kill 80% of the marketable oysters in specific production areas, and can affect younger oysters as well. Signs in affected oysters include pinhead ulcerations in the flesh, first in the palps, then the gills, and finally in the adductor muscle and gonad. Oysters then gape and die. Sprague (1971) has pointed out the similarity of these signs to European gill disease, and Mackin (1961) thinks that the mortalities result from *Labyrinthomyxa* infections.

Very recently, quite a different type of mortality occurred in *C. commercialis* in Moreton Bay, Queensland, and persisted for several years (Wolf, 1972). A sporulating haplosporidan, not further identified, was seen in tissues of moribund oysters and was considered to be responsible for the mortalities. This finding is significant, in view of the recent oyster mortalities on the United States east coast caused by haplosporidans, and of the recognition of haplosporidan infections in oysters from the United States west coast and from Korea. Recently, Perkins and Wolf (1976) have named the Australian oyster pathogen *Marteilia sydneyi*, placing it in the same genus as the parasite associated with digestive gland disease of the European *Ostrea edulis*.

6 Oyster mortalities in the Pacific islands

Mortalities in native and introduced oysters have been reported recently from islands of the South Pacific. Introduced *Crassostrea virginica* in Pearl Harbour, Hawaii, died during an epizootic of *Labyrinthomyxa* in the summer of 1972 (Kern, Sullivan and Takata 1973). Mortalities exceeded 90%, and high prevalence of a *Labyrinthomyxa*-like parasite was confirmed by culture and histological studies.

C. gigas in hanging culture in Fiji died in 1975 and 1976, with mortalities reaching 88% (R. M. Stone, communication to J. B. Glude). No pathogen was identified, and the cause was felt to be environmental stress. Similar mortalities of *C. gigas* in their second year of life occurred in Palau (Glude, personal communication).

Mortalities occurred in native mangrove oysters of French Polynesia, *C. glomerata*, in the early 1970's (Glude, personal communication). Histological examination did not disclose a pathogen.

All of these island mortalities are of course localized, and do not approach the dimensions of the mass deaths discussed in previous sections.

7 Conclusions

The twentieth century has been a troublesome period for oysters in many parts of the world. Decline in abundance of oysters actually started in the nineteenth century, probably caused in large part by a combination of poor setting, indiscriminate harvesting, and destruction of beds. Extensive mortalities from unknown causes also contributed to decreased oyster production. The rate of decline has accelerated within the past two decades, partly because of large-scale mortalities—several of which have been caused by infectious disease. Due to their worldwide economic importance, oysters are among the most thoroughly studied of marine animals, but unresolved problems remain. Mortalities constitute one such problem area.

Oysters die for many reasons. Mackin (1961) has attempted to classify types of mortalities based on their origin: (*i*) those caused by extremes of physical environmental factors; (*ii*) those caused by disease; (*iii*) those due to starvation; (*iv*) those resulting from spatial competition; (*v*) those due to predators; (*vi*) those due to toxins; and (*vii*) those due to metabolic competition. Certain general characteristics can be associated with each type. Unfortunately, an additional and very large category, 'those of unknown origin' is the one which, as Mackin admits, has 'produced the most spectacular declines in populations of oysters.' Probably there should be still another category: 'those of apparently complex origin' since it seems that at least some of the recent mortalities in Japan and on the west coast of the United States may involve environmental and physiological components, with the possibility of disease as a secondary factor. Mackin concludes, with some justification, that of all the causes of mortality, disease ranks first—both as a cause of spectacular major declines in production, and as a cause of much 'background' mortality.

Mass mortalities are receiving greater scientific attention now than in the past. For example, oyster mortalities in the 1960's in Matsushima Bay, Japan, resulted in a combined research effort by the Oyster Research Institute, the Prefectural Fisheries Co-operative, the Tohoku Regional Fisheries Laboratory and Tohoku University. Almost simultaneously, a large federally-funded co-operative research group consisting of state, university, and federal research groups was organized on the US Pacific coast to investigate oyster mortalities which were occurring there. The Pacific coast group, formed in the mid-1960's and guided by a steering committee chaired by John Glude of the National Marine Fisheries Service (Glude, 1975), probably represents a model for the structure of research response to a severe mortality problem, since it included expertise in environmental as well as pathological specialites, and provided for continuing co-operation of research.

What is needed badly—and this was pointed out by Sprague (1971) as well—is *continuity of research*, during quiescent periods as well as mortality periods. Examining mass mortalities while they are occurring can be an exciting experience, but it will be more useful if a chronicle of events preceding the mortalities is available. Insights often accumulate very slowly, sometimes long after populations have been decimated and the public has lost interest in the problem.

In addition to continuity of research, also needed is a *critical mass of scientific competences* to approach effectively any problem of mass mortality. Biology, chemistry, ecology, pathology, immunology, physical oceanography—all must be available initially, until some insights are gained which can give more precise direction to the investigations. It is very encouraging that during the past decade there has been a critical examination of major mortalities which have occurred in Europe, Japan and the United States.

Looking at the record of successes and failures in attempts to understand mass mortalities, it is not difficult to become discouraged. Often these 'visitations' have appeared, exerted major impact on oyster production, then dwindled away, while individuals or small groups of scientists have groped in vain for causative factors. This course of events has been true for about 75% of the major oyster mortalities in this century. However, there is some solace in those few instances (such as the *Labyrinthomyxa marina* research in the United States) where causative organisms were recognized, understanding of the life cycle was developed, and reasonably effective control measures were proposed.

Even though adequate insights about the origins of some mortalities are still lacking, there have been enough investigations, particularly during the past two decades, to allow certain generalizations to be made:

(*i*) Not all mortalities of oysters are caused by the activities of pathogens, but among the disease organisms identified as etiological agents of epizootics and concomitant mass mortalities there are two groups—the *Labyrinthomyxa*-like protistans, and the haplosporidans, particularly of the genus *Minchinia*—which are emerging as of world-wide significance. The *Labyrinthomyxa*-like organisms in particular may be of much greater significance to oyster populations than has thus far been demonstrated. In addition to numerous recent reports of such organisms in European oysters, there is also the observation of Quick and Mackin (1971) of a lethal oyster parasite—a second species of *Labyrinthomyxa*—associated with oyster mortalities in Florida which were originally thought to be caused by *Labyrinthomyxa marina* alone. Sprague (1971) also felt that the possible role of amoeboid *Labyrinthomyxa*-like organisms in heretofore unexplained mortalities had been underemphasized.

(*ii*) During times of mass mortalities, there is often pressure to assign a cause. The identification of a parasitic organism in the tissues of oysters is an important but very preliminary phase in the process of assigning blame for mortalities. The rigorous sequence of steps necessary to associate a pathogen with a disease is difficult to accomplish with marine organisms—particularly if the pathogen is not easily cultured. Without these steps it is possible to reach erroneous conclusions.

(*iii*) Mass mortalities may affect any stage in the life history of the oyster, from larva to adult. The early life stages are very vulnerable; recent experience in shellfish hatcheries (Davis *et al*, 1954; Tubiash, Chanley and Leifson, 1965) has demonstrated that larval mortalities are not uncommon; other studies have demonstrated the high mortality rate of spat in the first year of life (Walne, 1961; Westley, 1975). Walne found in a six-year study that mortality in the first year of life of *O. edulis*, after setting, varied between 66 and 92%. Westley was concerned with the fate of seed oysters planted on growing beds in Puget Sound, Washington. He found mortalities of about 62% during the first year after planting (partly due, of course, to smothering of seed on the underside of the cultch). On the other hand, very young oysters seem to be less vulnerable than older ones to mortalities caused by pathogens such as *Labyrinthomyxa* or *Minchinia*—at least during the first few months of life.

8 Recommendations for control of mortalities

Mortalities in natural oyster beds are not usually subject to control in the sense that populations in restricted aquatic environments may be controlled (*ie*, by water quality management, application of chemotherapeutic agents, *etc*). What is feasible, however, is the limitation of the extent of mortalities by: (*i*) *environmental manipulation* (cleaning beds of dead shells, selective removal of possible intermediate or reservoir hosts of pathogens, selective use of chemicals); or (*ii*) *stock manipulation* (moving oysters to low salinity growing areas, planting at prescribed low densities, suspending oysters at specific depths in the water column, moving oysters to waters with poor nutrient content for part of the growing season, planting seed late in the growing season, and harvesting oysters before annual mortalities are expected). In only one instance has chemical control been proposed; Korringa (1952) suggested disinfection of oysters with shell disease with organic mercury salt solutions. (Because of its toxicity to other organisms, use of mercury would not be recommended at present).

Usually, though, by the time control methods can be implemented, the peak of mortalities has been passed, and annual deaths have begun receding to background levels. Control methods developed can still be useful, however, in reducing that part of background mortalities that is attributable to the longer-term effects of specific pathogens. For example, control methods developed in the Gulf of Mexico for *Labyrinthomyxa marina* epizootics (reduced stocking densities, use of low salinity growout areas, and early harvest) are of continuing utility in suppressing annual and continuing mortality due to the pathogen.

Studies of two serious pathogens of oysters, *Labyrinthomyxa marina* and *Minchinia nelsoni*, have revealed the very important role of a 'salinity barrier' to certain diseases. *Labyrinthomyxa* exerts severe effects on oyster populations in high salinity waters of the bays along the Gulf of Mexico coast but does not flourish in low salinity areas. *Minchinia nelsoni*, which has seriously affected oyster stocks of the Middle Atlantic states, also occurs in higher salinities. Both pathogens seem most active in salinities above 15‰; this fact has made possible the continuation of production in parts of coastal areas affected by the epizootics.

Inhibitory effects of low temperatures have been well illustrated for these serious oyster pathogens. *Labyrinthomyxa* causes warm-weather mortalities in American oysters, in fact, the plantings of seed oysters are timed to take advantage of the relative quiescence of the disease in cooler seasons. Surveys of *Labyrinthomyxa* prevalences have indicated marked decline in winter. *Minchinia nelsoni*, of Chesapeake and Delaware Bays, is similarly quiescent in winter; new infections are not apparent, prevalence of disease declines, existing infections seem less active, and mortalities are reduced.

The development of resistance to particular infectious agents can be used as a method of control. Severe mortalities exert selection pressure favouring survival of individuals with some degree of resistance. Propagation of such individuals and re-exposure to the pathogen over a number of generations can lead to a stock which is resistant to at least the acute stage of infection. Such a sequence of events seems to have occurred in oysters of Prince Edward Island during the 'Malpeque Bay Disease' outbreaks. Some resistance seems to have been developed also in oyster stocks exposed and re-exposed to the haplosporidan *Minchinia nelsoni* in Delaware and lower Chesapeake Bay. Here infection levels have remained high, but mortalities have declined. Experiments have been underway in Virginia to propagate artificially, using hatchery methods, oysters resistant to *M. nelsoni*.

Another approach to problems of mass mortalities, is *replacement* of a susceptible species by another which is more resistant to infections or other agents identified as causes of continuing mortalities. This approach is being used (only partly by design) in France (Deltreil, 1973) where *Crassostrea gigas*, originally imported as seed from Japan, is replacing both *C. angulata* and *O. edulis* in some French oyster producing areas.

Control of mortalities may, of course, depend on special circumstances. The finding that a large reservoir of the fungus responsible for 'shell disease' of oysters lived in dead cockle shells led Korringa (1951) to propose, very logically, the removal of all dead shells from growing areas and the near vicinity, and to concentrate spat production in areas not heavily infected.

A final method to reduce mortalities is to grow oysters in closed systems, where environmental variables may be controlled.

Since oyster mass mortalities will undoubtedly occur in the future, as they have in the past, some measures useful in responding to the next major mass loss should be examined: (*i*) Governments should institute a continuing monitoring system for coastal species of economic concern, such as oysters. This monitoring should include, but not be limited to, surveillance of prevalences of known pathogens and predators. (*ii*) Some form of rapid funding response to marine environmental crises (such as mass mortalities) should be available. Even limited emergency funds can serve as a springboard for expanded research contributions by states (provinces), universities, and industry.

(*iii*) Co-ordination of research efforts is important, without inhibiting individual contributions by experts. Ingredients of such co-ordination include a steering committee and an *ad hoc* advisory committee from the industry segments being affected. (*iv*) The assembled research group should include as many disciplines as necessary. Since a number of mass mortalities of oysters have been associated with pathogens, pathology obviously must be a significant representation. However, environmental and physiological aspects must not be ignored, since mass mortalities can have complex etiology. (*v*) As quickly as possible, and even before adequate research information is available, empirical attempts to find ways to alleviate effects of mortalities should be instituted. These may take the form, for example, of placing test lots of oysters in different salinities, or at different depths, or in different densities.

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Cultivo del Mejillon, *Mytilus edulis*, y Posibilidades para su Expansión

A. Figueras

Extracto

El presente trabajo intenta reseñar los conocimientos actuales acerca de los factores biológicos, ambientales, socioeconómicos y tecnológicos relacionados con el cultivo de *Mytilus edulis* en distintos paises, y se subraya la necesidad de examinar estos parámetros antes de introducir el cultivo de mejillones a escala industrial.

Los mayores productores europeos de mejillón (*M. edulis*) son España, los Paises Bajos y Francia, cada uno de los cuales tiene su propio sistema de cultivo. También en Dinamarca, Italia y el Reino Unido se practica el cultivo del mejillón, pero su producción anual es inferior. Otras especies de mejillón se cultivan en Tailandia, Corea y Chile.

El método de cultivo en balsas desarrollado en España ha contribuido a incrementar la producción hasta tal punto que aproximadamente 40 a 45% de la actual producción mundial de mejillones (producción media del periodo 1970–74, unas 306 000 toneladas) se obtiene en este país.

En España se utilizan distintos tipos de bateas flotantes construidas con madera o recientemente con acero. La duración del material empleado en el tipo clásico de bateas es de dos a tres años, con un máximo de 10–12 años. Una batea de 25 × 15 m de superficie para 816 cuerdas de 8–10 m de longitud cuesta unos US$16 000. Las bateas de tales dimensiones pueden producir anualmente unas 60 toneladas de mejillones (peso en bruto), con un rendimiento de 23 toneladas de carne equivalente a 12,6 toneladas de carne cocida.

Culture of the mussel, *Mytilus edulis*, and possibilities for its expansion

Abstract

This paper attempts to review the available knowledge of the biological, environmental, socio-economic and technological factors related to the cultivation of *Mytilus edulis* in different countries, and emphasizes the need for considering these parameters before introducing mussel farming on an industrial scale.

The major mussel (*M. edulis*) producing countries in Europe are Spain, the Netherlands and France; each having its own system of culture. Mussel cultivation is also practised in Denmark, Italy and the United Kingdom, although only with lower annual production. Other species of mussel are cultured in Thailand, Korea and Chile.

The raft culture method developed in Spain has contributed to increasing production to such a degree that approximately 40–45% of the current world mussel production (mean production for the period 1970–74 about 306 000 tons) is obtained from that country.

A variety of floating rafts, constructed either with timber or recently with steel, are used in Spain. The life span of the material used in the classical type of floats is between 2 and 3 years with a maximum of 10-12 years. A raft having a surface area of 25 × 15 m for 816 ropes of 8–10 m length, costs about US$16 000. Rafts of such dimensions can produce annually about 60 tons of mussel, yielding 23 tons of meat equivalent to 12·6 tons of cooked meat.

L'élevage de la moule, *Mytilus edulis*, et possibilités pour son extension

Résumé

L'auteur fait le point des connaissances actuelles sur les facteurs biologiques, de milieu, socio-économiques et technologiques concernant l'élevage de *Mytilus edulis* dans différents pays et souligne la nécessité de prendre ces paramètres en considération avant d'entreprendre des opérations de mytiliculture à une échelle industrielle.

En Europe les principaux pays producteurs de moule (*M. edulis*) sont l'Espagne, les Pays-Bas et la France, chacun utilisant son propre système d'élevage. La mytiliculture se pratique aussi au Danemark, en Italie et au Royaume-Uni, encore que la production annuelle de ces pays soit faible. La Thaïlande, la Corée et le Chili cultivent des espèces de moules différentes.

La méthode de culture sur radeau, mise au point en Espagne, a permis de pousser la production à un degré tel qu'environ 40 à 45% de la production mondiale actuelle de moule (production moyenne pendant la période 1970–74: environ 306 000 tonnes) provient de ce pays.

L'Espagne utilise divers types de radeaux flottants, construits en bois ou, depuis peu, en acier. La durée de service des matériaux utilisés pour les radeaux de type classique se situe entre 2 et 3 ans pour atteindre au

maximum 10 à 12 ans. Un radeau d'une surface de 25 × 15 m dotés de 816 cordes de 8–10 m revient à environ US$16 000. Les radeaux de ces dimensions peuvent produire chaque année environ 60 tonnes de moules donnant 23 tonnes de chair de moule fraîche, équivalent à 12,6 tonnes de chair cuite.

1 Introducción

El tema sobre el cultivo del mejillón ha sido tratado con anterioridad por muchos autores entre los cuales se señalan principalmente los trabajos de Andreu (1968, 1968a); Bardach, Ryther y McLarney (1972); Davies (1970); Hurlburt (1974); Iversen (1968); Korringa (1970); Mason (1972); Waugh (1966); Wiborg y Bøhle (1968) y otros.

La finalidad de este trabajo es: (*a*) colaborar en la obtención de mayores rendimientos y mejoras en la tecnología de su aprovechamiento y cultivo en aquellas áreas donde la mitilicultura está desarrollada, (*b*) orientar sobre los cambios convenientes en el perfeccionamiento del sistema de cultivo actual en otras áreas donde hasta ahora el rendimiento no alcanzó el nivel de producción factible y (*c*) ayudar en la elección e implantación del método más eficaz de cultivo allí donde en la actualidad éste no exista a pesar de condiciones apropiadas.

2 Cultivo

Según la clasificación hecha por Kinne (1970) los cultivos marinos comprenden cuatro grados: (*i*) 'maintenance' (=mantenimiento): simple estabulación o depósito sin crecimiento apreciable con fines científicos o comerciales, (*ii*) 'raising' (=engorde) o mantenimiento con aumento de peso de jóvenes o adultos, (*iii*) 'rearing' (=recría) o desarrollo a partir de los primeros estadios ontogénicos (huevos fecundados, larvas) y (*iv*) 'breeding' (=cría) que comprende la producción, el desarrollo y engorde.

He aquí nuestra clasificación: (*a*) cultivo integral, cuando en él se cumplen la producción, el desarrollo y el engorde ('breeding'), (*b*) semicultivo, cuando sólo se practica el desarrollo y engorde ('rearing'), (*c*) depósito o mantenimiento, cuando sólo se realiza el engorde ('raising'/'maintenance').

Los principios básicos y ventajas de todo cultivo fueron resumidos por Mason (1972). En una parte de su trabajo expresa que 'la exclusiva producción de larvas es, a menudo, la parte más difícil y costosa, por lo cual sólo se realiza para aquellas especies de precio elevado, que no es precisamente el caso del mejillón'. Por esta razón él considera el cultivo del mejillón como perteneciente al segundo grado de la clasificación de Kinne (1970, 'raising'). Sin embargo, en el cultivo como se practica en España, los progenitores se tienen en el mismo parque de cultivo. Estos se reproducen dando origen a larvas, que se obtienen adheridas a cuerdas colectoras. Tal cultivo pertenece al cultivo integral o la 4ª categoría ('breeding') según Kinne.

Estos principios podrían servir también para definir el tan discutido concepto de 'banco natural de moluscos'.

2.1 *Métodos*

Las descripciones de los métodos están en los trabajos de Andreu (1968), Mason (1972) y Hurlburt (1974). Los métodos principales y el país de Europa donde estos se practican con mayor intensidad son los siguentes: (*i*) cultivo sobre el fondo en Holanda, (*ii*) cultivo sobre postes: (*a*) cultivo integral 'a flote' en la costa atlántica meridional de Francia, (*b*) semicultivo 'a pie', en la costa atlántica septentrional de Francia, (*iii*) cultivo sobre cuerdas colgantes: (*a*) cuerdas fijas en la costa mediterránea (Francia, Italia), (*b*) cuerdas flotantes en la costa atlántica y mediterránea (España).

Todos los países citados obtienen una buena producción del mejillón con cada uno de los sistemas mencionados, ya que se adaptan a sus peculiares características. Andreu (1968) piensa que cada sistema de cultivo será más o menos idóneo, según las circunstancias geográficas de producción primaria y biológicas de las respectivas especies.

2.2 *Factores a tener en cuenta para su implantación*

La introducción de nuevos métodos de cultivo a nivel industrial suscita ciertas dificultades que deben preverse oportunamente y el ejemplo más reciente de Nueva Zelandia (2.3.3), New Zealand (1971) es buena prueba de ello. No basta exclusivamente tomar en cuenta los altos valores de producción (2.4).

2.2.1 *Biología de la especie*

(*a*) Sistemática y distribución

El género *Mytilus* está prácticamente extendido por todo el mundo, alternando o conviviendo con otros géneros y especies afines tales como el género *Perna* en Venezuela, Africa atlántica y Nueva Zelandia, el *Choromytilus* en Chile, etc. Las poblaciones naturales de *Mytilus edulis* están distribuidas desde el Océano Artico hasta las costas africanas, desde el Río Grande (Brasil) hasta el Estrecho de Magallanes; en el Pacífico desde Alaska hasta California y las costas de Chile.

Varias de las especies del género *Mytilus* son objeto de cultivo. En Europa se cultivan el *M. edulis* y el *M. galloprovincialis*; en Chile existe el *M. edulis chilensis* y en Nueva Zelandia el *M. edulis aeotanus*; en Filipinas el *M. smaragdinus*; en India el *M. grayanus* y el *M. viridis*; en Corea el *M. coruscus* y el *M. crassitesta*; en Australia el *M. edulis* en la costa meridional y suroccidental y *Trichomya hirsuta* en la oriental (Andreu, 1968; Mason, 1972).

(*b*) Ecología

Las condiciones ambientales que determinan la supervivencia de las especies varían según las latitudes. Los valores de estos factores tienen límites amplios y han sido estudiados principalmente por Kanwisher (1955), Loosanoff (1942), Renzoni (1961, 1963), Seed (1969), Segerstrale (1957), White (1937), etc., recopilados por Mason (1972).

El efecto de la luz sobre el crecimiento del mejillón es importante según Huntsman (1921) y Coulthard (1929). Insolaciones de baja intensidad estimulan el crecimiento. El peso medio de los mejillones mantenidos en la oscuridad fué un 26% superior a los de penumbra y un 70% a los de la luz. Los individuos mantenidos en penumbra tuvieron un peso medio de un 33% superior a los de la luz (Andreu, 1960).

(*c*) Fisiología

Reproducción: Mytilus edulis está sexualmente maduro a la edad de un año según la mayoría de los autores (Field, 1922; White, 1937; Seed, 1969). Sin embargo, el mejillón de la ría de Vigo empieza a madurar sexualmente cuando su talla alcanza unos 40–50 mm, lo que corresponde a los 6–7 meses de edad, según la época de puesta de que proceda.

Chipperfield (1953) estableció claramente la separación por sexos, lo cual no excluye que a veces puedan encontrarse individuos hermafroditas (Figueras, datos inéditos). La puesta más importante en casi toda Europa es en primavera pero en las costas de Galicia (España) se presentan dos importantes y dilatadas épocas de puesta; una en primavera con fijaciones desde abril hasta julio, y otra en otoño con fijaciones desde octubre hasta febrero. Prácticamente, puede decirse que hay mejillones sexualmente maduros durante todo el año. Todas estas diferencias nos hacen pensar en la necesidad de proseguir con los estudios de la reproducción de dicha especie en diversas partes del mundo.

Crecimiento: Según las latitudes geográficas y las condiciones ambientales (luz, salinidad, temperatura, producción primaria, régimen de corrientes, etc.) el crecimiento de *M. edulis* varía (Andreu, 1958). Mientras en Galicia llega a la talla comercial (80–90 mm) en un año o año y medio, en Francia alcanza los 40–50 mm, talla comercial establecida, a los 2 años. A los 3 años alcanzan en Holanda 72 mm y en Inglaterra 54 mm. Con 5 años de edad logran en Gales 61 mm y en Canadá 63 mm (Andreu, 1958).

Según Fraga (1956) el período de engorde (medido por el aumento de glucógeno) va en España desde febrero hasta octubre (8 meses) y en Holanda desde mayo hasta agosto (4 meses). El mejillón de la ría de Vigo alcanza su peso máximo entre los meses de septiembre y diciembre. Los mejillones grandes mantienen el peso durante mayor número de meses (Andreu, 1963).

Alimentación: El mejillón *M. edulis* de la ría de Vigo se alimenta de materia orgánica donde el fitoplancton, representa sólo el 14% del total (Fraga, 1958).

Tasa de filtración o de bombeo: Esta especie puede filtrar de 2 a 5 litros de agua por hora según las condiciones del individuo (Andreu, 1958). Los individuos de una cuerda son capaces de filtrar al día no menos de 90 000 litros de agua y los de todo un parque flotante alrededor de 70 millones de litros en el mismo tiempo (Andreu, 1963). Los mejillones de un parque flotante mediano pueden por lo tanto ingerir 180 toneladas de materia orgánica al año, de las cuales unas 100 toneladas son devueltas al mar en forma de heces. La acumulación de tales detritos sobre los fondos pone en peligro la supervivencia de otras especies del bentos. Esto ha sucedido en algunas áreas conocidas, hasta hace poco, como los bancos naturales de ostra plana más ricos de Europa. Hay que prestar, pues, atención a los problemas que pueden resultar en consecuencia 'del cultivo indiscriminado' del mejillón 'a flote' en áreas donde existen otras especies de alto valor comercial (Andreu, 1974). Recientemente también el profesor Uno de la Universidad de Tokyo, en sú visita a Vigo, ha advertido otros inconvenientes de un monocultivo demasiado intensivo.

Enfermedades, parásitos, competidores y enemigos: Nuestros conocimientos son más bien reducidos respecto a las enfermedades del *M. edulis*. Recientemente se ha seguido más de cerca una enfermedad de las branquias, pero que afectaba principalmente a la ostra.

El parásito mejor conocido que ha causado mayores daños, por ejemplo entre los mejillones cultivados en Holanda e Inglaterra, es el crustáceo copépodo *Mytilicola intestinalis* (Korringa, 1950, 1951, 1952). Afortunadamente en España a pesar de un cierto grado de infestación relativa (Figueras, datos inéditos) ésta no ha llegado a extremos alarmantes y no se han notado los efectos sobre el estado de condición de los individuos. Andreu (1960, 1963, 1965) destaca que la infestación es mayor en áreas próximas a la desembocadura de los estuarios y en los parques flotantes de cultivo próximos a tierra que en aquéllos situados alejados de la orilla. También se debe destacar que la infestación vertical (a lo largo de la cuerda) no varía apreciablemente en áreas de fuerte corriente de marea, mientras que el número de parásitos aumenta con la profundidad en aguas de relativa tranquilidad. El porcentaje de *M. edulis* atacados por *Mytilicola* aumenta proporcionalmente con la talla de los individuos. En los mejillones menores de 20 mm no se encontraron parásitos (Andreu, 1960). El peso medio de los moluscos desconchados es inversamente proporcional al número de *Mytilicola* existentes en el tubo digestivo (Andreu, 1965). Teóricamente cada parásito puede ocasionar una pérdida del peso medio del cuerpo de un 1%. La vida media de los parásitos es alrededor de 3 meses pero pueden alcanzar 6 meses de edad. Durante todos los meses del año se puede encontrar un elevado porcentaje de hembras con sacos ovigeros (Andreu, 1963).

En cuanto a los organismos competidores e incrustantes los más importantes en la ría de Vigo son: la ascidia *Ciona intestinalis* y las algas del género *Ulva, Enteromorpha, etc.* como competidores en la cuerda; mientras que los crustáceos y poliquetos, *Elminius modestus, Pomatoceros triqueter* respectivamente y el briozoo arborescente *Bugula neritica* representan incrustantes sobre las valvas del mejillón.

Por ahora el mejor modo de combatir las ascidias y las algas parece ser una moderna máquina de limpieza que ya se emplea para las ostras. Consiste en un cilindro en el cual están dirigidos chorros de agua a presión; es eficaz y no perjudica a los animales. Para combatir la fijación de los incrustantes el cultivo tendría que condicionarse a la acción de la luz. Según Andreu (1960) *Pomatoceros* se fija preferentemente en la oscuridad al revés de *Elminius* que prefiere las zonas iluminadas. Observando las épocas de fijación de uno y otro se podrían obtener las valvas de *M. edulis* sin organismos incrustantes.

Como ejemplo de algunos enemigos se pueden enumerar, el molusco *Thais lapillus,* el equinodermo *Asteria rubens,* las aves *Larus argentatus* y *L. fuscus,* etc.

2.2.2 *Condiciones ambientales en el área del cultivo.* Las principales a tener en cuenta son: (*i*) *salinidad* estudiar las variaciones y en qué cuantía y época del año se producen, y hasta qué profundidad de la superficie alcanzan. Considerar si hay inversión térmica en la estación lluviosa: (*ii*) *temperatura* de las aguas y sus variaciones extremas a lo largo del año; (*iii*) *luminosidad* ambiente, recuérdese la influencia de la luz tanto en el crecimiento como en la fijación de organismos incrustantes y competidores (Andreu, 1960b); (*iv*) *energía incidente,* por su influencia primordial junto con la circulación del agua y el aporte de nutrientes, en la producción primaria; (*v*) *producción primaria* y tasa de *materia orgánica* particulada; (*vi*) *condiciones de abrigo* suficientes para la seguridad de los artefactos de cultivo y del mismo mejillón; (*vii*) *circulación del agua* suficiente que permita una buena renovación, pero que no tenga una excesiva velocidad de corriente; (*viii*) ausencia en el agua de *partículas minerales en suspensión.*

2.2.3 *Factores socioeconómicos.* Los factores socioeconómicos a tener en cuenta son:
(*i*) *la disponibilidad y el costo de la mano de obra.*

En el Plan Indicativo para el Desarrollo Agrícola se consideró que los mejillones 'constituyen un medio excelente para responder a la necesidad de alimentos proteínicos, no sólo por su bajo precio al consumidor, sino porque además, el principal componente de su producción es la mano de obra' (Anon., 1970).

Webber (1968) y otros autores consideran que uno de los mayores inconvenientes para poner en práctica el cultivo 'a flote' es el elevado costo de la mano de obra en los países de mayor desarrollo económico. Por nuestra parte consideramos que la mecanización en el proceso de cultivo irá progresando y mejorando las condiciones laborales al igual que ha sucedido en otras fuentes de producción agrícola o industrial.

(ii) la existencia, magnitud y exigencias cualitativas del mercado actual o potencial

(iii) el precio de venta remunerador

La afirmación de Mason (1972)—que también recoge Bardach *et al* (1972)—de que en la industria mejillonera de España al aumentar la producción ha disminuido el precio precisa alguna aclaración. Un ligero descenso del precio unitario no implica necesariamente una reducción de los beneficios. La prueba evidente es que la industria mejillonera española, no ha disminuido o estancado las actividades en los últimos tiempos, sino que la curva de la producción y de la construcción de nuevas instalaciones va en aumento—quizás de un modo demasiado acelerado—en detrimento del cultivo de otras especies de mayor rentabilidad y necesarias para el equilibrio ecológico de las rías. Al socaire de dicha industria han proliferado también un buen número de otras nuevas industrias (estaciones depuradoras, cocederos de mejillón, frigoríficos, *etc*). Se ha incrementado la exportación tanto en fresco como en conserva; se regulan los stocks mediante el congelado; se han constituido grandes firmas de comercialización, *etc.* Finalmente en los últimos años, el precio de primera venta del mejillón se ha revalorizado.

(iv) la disponibilidad y el costo de los materiales para la construcción de los artefactos (instalaciones) o las operaciones de cultivo (2.2.5)

Uno de los ejemplos clásicos es la disponibilidad de la 'redecilla' para sujetar el mejillón a la cuerda. A este respecto es ilustrativa la experiencia de Nueva Zelandia (2.3.3).

A título indicativo se exponen a continuación algunos datos sobre el costo y mantenimiento de las instalaciones actuales en España:

(i) La instalación de artefactos flotantes: Un parque flotante (mediano) con accesorios y anclado viene a costar entre US$ 15 000 y 20 000[1]. Acaban de salir al mercado nuevos tipos de parques flotantes con vigas de flotación rellenas de poliuretano expandido, vigas del entramado del mismo material y huecas. Los de superficie 25 × 15 m con una capacidad para 816 cuerdas de 8 a 10 m y un peso de 200 toneladas cuestan unos US$ 16 000 (al cambio citado).

Otro nuevo tipo de parque es el construido con vigas y perfiles de acero naval y 4 flotadores de forma semiesférica fabricados por moldeo de contacto a base de poliester, tejidos especiales y fibra de vidrio. El anclaje se puede hacer en forma de estrella en varios puntos de la parrilla. Sus dimensiones son de 16 × 16 m con un 87% de superficie útil y un peso de 10 toneladas. La capacidad es de 80 a 100 toneladas de mejillones sumergidos de talla comercial.

(ii) El mantenimiento: La mano de obra utilizada en los cultivos es de empleo fijo o eventual pero cada vez más está ganando terreno el empleo fijo al dejar de ser una ocupación de tipo familiar para convertirse en una empresa industrial. De un reciente estudio económico se dedujo que la rentabilidad mínima de explotación se puede obtener con un mínimo de 6 parques flotantes.

(iii) El material usado en la construcción de los parques flotantes es el clásico hecho de madera revestido con cemento, tiene un período de carencia entre 2 y 3 años y una duración máxima (promedio) de 10 a 12 años; algunos tienen más de 20 años de existencia.

Uno de los problemas importantes son las pérdidas causadas por las sacudidas de los temporales en particular en determinadas áreas más expuestas. Las compañías de seguros, que hasta hace poco no se hacían cargo de estos riesgos, están en la actualidad estudiando esta posibilidad. Las pérdidas por este concepto afectaban alrededor del 1 o 2% de parques flotantes y unas pérdidas medias de US$ 2 000 por cada parque afectado lo que hace aproximadamente el total anual de unos US$ 120 000.

En la actualidad la estructura organizativa de la industria mejillonera española está dividida entre los siguientes niveles: (*a*) *la producción,* con una base mínima de 10 parques en explotación, está normalmente compartida con otras industrias subsidiarias o de manipulación (estaciones de depuración, cocederos, fábricas de conserva, *etc.*); (*b*) *la manipulación* comprende las estaciones de depuración, cocederos, frigoríficos, fábricas de conservas, preparación de platos precocinados (ejemplo 'paellas') *etc.* (*c*) *en la comercialización* se están organizando empresas que controlarán un elevado porcentaje de la producción de materia prima, tanto en fresco como en conserva, para el mercado nacional e internacional.

2.2.4 *Factores jurídico-administrativos.* Según las circunstancias de los países las normas legales favorecen en unos y se oponen en otros a la implantación del cultivo. De las experiencias pasadas se puede suponer que habrá que arbitrar los instrumentos legales pertinentes a la medida que la industria del cultivo y las industrias anejas vayan presentando sus particularidades.

Todos los sistemas de cultivo del mejillón confluyen en la jurisdicción de varios departamentos gubernamentales. En España, por ejemplo, existe una reglamentación elaborada por comisiones interministeriales en las que intervienen representantes, entre otros, de sanidad, obras públicas, sindicales, científicos, autoridades marinas, etc. A la hora de decidir las zonas aptas para el cultivo habrá que contar con los representantes de turismo y de agricultura que también tienen que ver con el dominio marino. Las concesiones o autorizaciones las otorgan normalmente la Dirección General de Pesca, que en España depende del Ministerio de Comercio. Existe una previa determinación de zonas de interés preferencial bien para el cultivo 'marisquero', bien para el turismo, agricultura, etc. En la actualidad está vigente un Plan de Explotación Marisquera de Galicia de cuya competencia son los cultivos marinos entre ellos el del mejillón.

2.2.5 *Factores tecnológicos.* Se hace principalmente la descripción del sistema con cuerdas colgantes a flote por ser

[1] US$ 1,00 = Pts. 50

el que mejor conocemos y el que presenta también la máxima complejidad y costo.

La producción: El elemento primordial y más costoso de las instalaciones es la batea ('raft' en inglés, 'radeau' en francés, 'xangada' en portugués y 'balsa' en español). Sus principales elementos son: un *emparrillado* cuadrado o rectangular de donde penden las *cuerdas* sostenido en el agua por medio de uno o varios *flotadores*. Estos artefactos pueden ser construidos para el propósito, pero también se pueden aprovechar y adaptar cascos viejos de embarcaciones de madera. Entre las ventajas de éstos últimos están la reducción en gastos de compra y de adaptación, resistencia al mal tiempo, capacidad y la uniformidad de crecimiento del mejillón en toda su superficie. Actualmente es difícil encontrar embarcaciones de madera destinadas al desguace.

Otros tipos de parques flotantes están descritos por Andreu (1968), Mason (1972) y Hurlburt (1974).

Cada batea se *fondea* a uno o dos 'cuerpos muertos' con cadena gruesa del desguace. Los 'cuerpos muertos' suelen ser de hormigón armado de forma prismática y de unas 6 toneladas o más de peso. En fondos limosos estos pueden ser más pequeños, ya que al enterrarse el amarre resulta más seguro.

Las *'cuerdas'*, empleadas en España, constan de dos partes. La parte superior que va atada al emparrillado y alcanza hasta los 20–40 cm por debajo de la superficie del agua se llama 'rabiza'. Es una cuerda estrecha, muy resistente, de material sintético. El resto de la cuerda donde se adhiere el mejillón es de unos 3 cm de diámetro y conviene que tenga una superficie rugosa. En la actualidad estas cuerdas son de material sintético (antes de esparto embreado) pero fabricadas con las fibras sintéticas filamentosas que tienen características muy parecidas a las anteriormente usadas; además su duración, resulta prácticamente ilimitada.

La cuerda empleada para la captación de semilla ('cuerdas blancas' o 'colectores') son redes viejas estiradas, preferiblemente de hilo grueso.

Las cuerdas llevan atravesadas, a trechos aproximados de unos 30 cm barrotes de madera llamados *'palillos'* (listones cuadrangulares de 2 cm en cada lado y una longitud de 30 a 40 cm).

Para fijar el mejillón a la cuerda se emplea una *'redecilla'* de características especiales (fabricada en España por Giro, S.A. en Badalona, Barcelona) en carretes de 100 y de 200 m (100 metros las de algodón y 200 las de viscosa y rayon) a un precio de unos US$ 1.

También se ha patentado en España un sistema para sustituir la cuerda y la redecilla, consistente en una manga de material sintético resistente, cuya malla es más o menos laxa. La materia usada en su fabricación es diferente de la patentada en Noruega y ensayada con éxito por Bøhle (1970) pero en España todavía no se ha generalizado su empleo.

Para el transporte del mejillón se emplean *sacos* de 'netlon' con una capacidad de 15 kg de color amarillo después que el mejillón ha pasado por una estación depuradora; los demás son de otros colores. La pérdida de peso que el mejillón sufre durante el transporte se calcula en un 10%.

Para evitar las pérdidas de mejillones por deslizamiento, al sacar la cuerda del agua, se han ideado diversos artefactos, de los cuales el *'cesto basculante'*, accionado por un torno o maquinilla ha tenido mayor aceptación.

Las operaciones de cultivo están descritas en el Cuadro I. Estas se realizan a lo largo del año según la temporada de la puesta (primavera u otoño). Las principales operaciones son las siguientes:

Obtención de semilla: Estas se adquieren de 'los mariscadores' que las arrancan de las rocas del litoral a principios de primavera o en otoño o bien se colocan cuerdas ('colectoras') alrededor de las bateas en primavera (la fijación de otoño no se presenta en las cuerdas).

Colocación de la semilla en la cuerda: Un puñado de semilla se coloca junto a la cuerda donde se les venda con la 'redecilla'. En el Cuadro II están los datos aproximados de la talla, peso y número de mejillones por kilogramo y metro de cuerda.

Desdoble: Con esta operación se quita el mejillón de una cuerda, se limpia y distribuye de nuevo entre dos o tres cuerdas nuevas. Estas cuerdas son más finas (por ello en inglés la operación se llama 'thinning'). Dicha operación tiene doble finalidad, por una parte limpiar el mejillón del fango, algas y demás incrustantes y/o competidores y por otra reducir el número de mejillones por unidad longitudinal de cuerda; ambas cosas favorecen su crecimiento. La colocación del mejillón en la cuerda nueva se hace igual que con la 'semilla' (Cuadro II).

Cosecha: Al término del período de tiempo según las condiciones de la zona, el tamaño legal mínimo exigido y las exigencias del mercado, se procede a quitar el mejillón comercial de la cuerda y prepararlo para su venta. La separación se hace con repetidas sacudidas de la cuerda. Ciertas industrias poseen maquinaria apropiada para la limpieza y separación mediante cuchillas que cortan los bisos. De este modo no se daña al mejillón y se ahorra mano de obra (Cuadro II).

La depuración: El mejillón retiene en su intestino bacterias patógenas procedentes de las aguas residuales de la tierra (Castellví, 1971, 1972). Para evitar la contaminación por el consumo de mejillones en crudo, se han establecido por iniciativa privada varias estaciones depuradoras. La depuración es obligatoria para todos los bivalvos que tengan que consumirse en crudo.

Los principales agentes esterilizadores del agua que se emplean son: el cloro (como gas o en solución), el ozono, las aguas oceánicas previa decantación y exposición a la acción solar y los rayos ultravioletas. Aunque no es necesaria la limpieza interna de partículas de fango, como en aquéllos provenientes de las áreas donde se cultiva directamente sobre el fondo, la depuración realiza ambas funciones a la vez.

En las depuradoras se verifica al mismo tiempo también la operación del 'endurecimiento', dejando durante algunos períodos de tiempo el mejillón en seco a fin de endurecer su músculo aductor y hacerle más resistente para soportar después un transporte más prolongado.

Las características principales de dichas estaciones y del procedimiento de depuración son: (*i*) tiempo de estancia: entre 36 y 48 horas; (*ii*) capacidad de depuración: entre 40 y 60 toneladas al día; (*iii*) superficie de tanques o piscinas: 1 500–3 000 m^2; (*iv*) cantidad máxima: 30 kg de mejillón/m^2 (*v*) capacidad de bombas de agua de mar: entre 300 y 500 m^3/hora; (*vi*) costo de mantenimiento diario: entre Pts. 7 000 y 15 000/día (US$ 140–300); (*vii*) cada estación efectúa en su propio laboratorio control bacteriológico del agua de mar y de la carne del mejillón a la entrada y salida

CUADRO I

ESQUEMA DE LAS OPERACIONES QUE SE REALIZAN MEDIANTE EL CULTIVO CON CUERDAS COLGANTES EN PARQUES FLOTANTES ESPAÑOLES

Meses	*Cría de otoño*		*Cría de primavera*	
	Operaciones	*Talla mm*	*Operaciones*	*Talla mm*
Oct.[b]	Puesta			
Nov.	Puesta			
Dic.	Fijación en rocas			
Ene.	Colocación semilla en cuerdas			
Feb.	Colocación semilla en cuerdas		Puesta	
Mar[b]	Crecimiento	8[a]	Puesta	
Abr.	Crecimiento	15	Colocación cuerdas colectoras	
May	Crecimiento	22	Fijación cuerdas y rocas	
Jun.	Crecimiento	31	Crecimiento	7[a]
Jul.	Desdoble	44	Colocación semilla en cuerdas	
Ago.	Desdoble	54	Colocación semilla en cuerdas	17
Set.[b]	Crecimiento	57	Desdoble	38
Oct.	Crecimiento	65	Desdoble	47
Nov.	Crecimiento	68	Desdoble	52
Dic.	Crecimiento	70	Desdoble	55
Ene.	Crecimiento	73	Desdoble	58
Feb.	Crecimiento	76	Crecimiento	60
Mar.[b]	Venta clase C (80 mm)	78	Crecimiento	65
Abr.	Venta clase C (80 mm)	80	Crecimiento	66
May.	Venta clase C (80 mm)		Crecimiento	
Jun.	Venta clase B (85 mm)		Crecimiento	
Jul.	Venta clase B (85 mm)		Crecimiento	
Ago.	Venta clase A (90 mm)		Crecimiento	
Set.[b]	Venta clase A (90 mm)		Venta clase C (80 mm)	
Oct.	Puesta		Venta clase C (80 mm)	
Nov.	Puesta		Venta clase B (85 mm)	
Dic.	Fijación en rocas		Venta clase B (85 mm)	
Ene.	Colocación semilla en cuerdas		Venta clase A (90 mm)	
Feb.	Colocación semilla en cuerdas		Puesta	
	etc.		*etc.*	

[a] Según Andreu (1958)

[b] La temporada de exportación al extranjero va desde septiembre a marzo, ambos inclusive

CUADRO II

ATOS DE TALLA, PESO Y NÚMERO DE MEJILLONES POR KILOGRAMO Y METRO DE CUERDA Y PESO APROXIMADO DE LA CUERDA 'LLENA' EN CADA OPERACIÓN

Operación	*Talla mm*	*Peso de los individuos gr*	*Número/ kilogramo*	*Número/m de cuerda*	*Peso por cuerda de 10 m[a] kg*
Colocación de la 'semilla' en la cuerda	10–12	0,25	4 000	6 000	15
'Desdoble'	40	5,0	200	300	15
Cosecha:					
—Clase 'C'	80	40,0	25	300	120
—Clase 'B'	85	45,0	22	300	135
—Clase 'A'	90	50,0	20	300	150

[a] La longitud de la cuerda varía entre los 6 y 10 m siendo 8 m la longitud media que empleamos para hacer los cálculos

de la estación bajo la responsabilidad de un facultativo supervisado por los Inspectores de Sanidad.

Normalmente los mejillones vivos y depurados se transportan en camiones refrigerados o por ferrocarril en vagones refrigerados. Cada vez se mecaniza más esta manipulación a fin de obtener un trato más delicado para el mejillón vivo y conseguir así una mejor calidad del mejillón fresco. Actualmente se están ensayando nuevas técnicas para la mejora del transporte (Vyncke y Debevere, 1969; Drinkwaard, 1972, 1975; Brunner y Houwing, 1974).

El consumo: El mejillón español se distribuye para el consumo en la proporción siguiente: el 40% de la producción se consume en fresco (destinándose el 10% a la exportación y el 30% restante al mercado interior) y el 60% restante se destina a la conserva. No se conoce la cantidad del mejillón conservado que se consume en el mercado nacional y la cantidad que se exporta. Los países importadores de mejillón fresco son en la actualidad Francia e Italia. Algunos países están elaborando productos del mejillón que por ahora se consideran como alimentos medicamentosos. También se emplea el mejillón congelado en platos precocinados.

2.3 *Algunas nociones sobre el estado actual por países*

2.3.1 *Europa.* Hay tres países de máxima producción de mejillones (España, Holanda y Francia), cada uno con un sistema de cultivo diferente (2.1) y descritos respectivamente por Andreu (1968), Mason (1972), Hurlburt (1974), Bardach, Ryther y McLarney (1972) y otros. También se practica la mitilicultura con producciones menores en Inglaterra, Italia, Portugal, Noruega (Bøhle y

Wiborg, 1967; Bøhle, 1970, 1971), Escocia (Mason, 1972), Dinamarca (Boetius, 1962), Alemania (Meixner, 1971) y Yugoslavia (Brenko, 1967).

2.3.2 *Las Américas.* En Venezuela y Chile hay una incipiente industria de mitilicultura. En Venezuela se han realizado progresos considerables siguiendo el sistema de cuerdas colgantes a flote según trabajos de Salaya, Beauperthuy y Martínez (1973) y Mandelli y Acuña (1975).

El desarrollo de la mitilicultura en Chile (Padilla, 1973; López-Capont, 1974) se encuentra en la actualidad en una fase preindustrial. López-Capont (1974) menciona que en Argentina están muy avanzados los trabajos para montar en la Laguna de Mar Chiqueta (Provincia de Buenos Aires) un centro experimental que tendrá a su favor la facilidad de controlar o modificar salinidades, recoger muestras, hacer plantaciones, etc.

En los Estados Unidos se están haciendo recientemente intentos para la implantación de este cultivo; uno en la costa atlántica (Hurlburt, 1974) y otro en la costa del Pacífico, cerca de Seattle, donde todavía está en fase de construir las instalaciones.

2.3.3 *Asia, Africa y Oceanía.* Hay informaciones sobre el cultivo del mejillón en Corea, probablemente cultivado sobre el fondo y por medio de cuerdas colgantes. En el año 1964 se dedicaban a este cultivo alrededor de 109 ha que produjeron en aquel año unas 963 toneladas (Folsom, 1974), mientras que en 1972 se producían 14 070 toneladas. Esto hace suponer un aumento paralelo en la superficie dedicada al cultivo o el paso progresivo al cultivo colgante. Algunos industriales que conservan mejillón de España, han acusado la presencia del mejillón coreano en los mercados europeos. Bardach, Ryther y McLarney (1972) informan sobre los trabajos de mitilicultura en Filipinas, Kampuchea, Taiwán provincia de China y Tailandia.

Al igual que en Japón, los cultivadores de ostras filipinos consideraban el mejillón *Mytilus smaragdinus*, como un competidor indeseable, pero ahora parece ser que este mejillón va a sustituir a la ostra como especie principal de cultivo, debido al descenso de la fijación natural de semilla de ostra. La Comisión de Pesca se encargó (1962) de iniciar las experiencias de cultivo y de hacer una campaña a favor del consumo del mejillón. El mejillón *M. smaragdinus* tiene un ciclo biológico muy parecido al del *M. edulis*. El cultivo se realiza colocando los colectores (conchas o trozos de bambú) con semilla adherida, en bandejas de 2×1 m. Las bandejas se suspenden de los postes a una altura de unos 30 cm sobre el fondo, quedando así sumergidos permanentemente. Los cultivadores del área de Bacoor prefieren el cultivo en postes, en vez del cultivo en balsas flotantes propugnado por la Comisión de Pesca, porque pueden adquirir los materiales necesarios más fácilmente en las proximidades del área de cultivo. Los mejillones se comercializan a una talla entre los 3 y los 8 cm (a los 4–10 meses de edad) tamaño preferido por el consumidor filipino.

En 1966 estaban en cultivo unas 8 ha con una producción de 2 000 toneladas de mejillón desconchado (unas 1 000 toneladas de carne o 125 toneladas/ha). Con el cultivo en cuerdas colgantes sería posible una producción de carne de más de 250 toneladas/ha.

Los dos principales problemas con que se enfrenta la mitilicultura en Filipinas en la actualidad parecen ser: (*a*) el ataque de los postes de bambú por *Teredo* sp. con el consiguiente derrumbe de los mismos y la pérdida de los mejillones, (*b*) la posibilidad de que llegue a escasear la semilla si se esquilman los bancos naturales sin haber logrado el aumento de su producción mediante colectores artificiales. Se están verificando trasplantes de mejillón adulto en la Bahía de Manila y en otras partes de Filipinas a fin de ampliar el área de fijación.

En Africa existe la mitilicultura en Túnez (Ricci, 1955) y los ensayos que Seita Machado hizo en Angola quedaron probablemente interrumpidos después de su fallecimiento.

En Nueva Zelandia se cultiva tanto el mejillón azul (*Mytilus edulis*) como el 'labiado verde' (*Perna canaliculus*). El caso de Nueva Zelandia ilustra las dificultades al intentar implantar un nuevo sistema de cultivo. Las vicisitudes experimentadas vienen reseñadas en New Zealand (1971), Waugh (1966) y otros. Se intentó cambiar el cultivo que hasta 1965 se realizaba sobre el fondo por el de cuerdas colgantes a flote al disminuir de modo alarmante la producción. Las condiciones a favor eran según Waugh (New Zealand, 1971) las siguientes: existencia de áreas abrigadas en abundancia, poca contaminación de las aguas litorales que haría innecesaria la depuración, la existencia de especies de crecimiento rapidísimo (*Perna canaliculus*), un mercado local extenso y en la actualidad insuficientemente abastecido lo que haría innecesario tener que depender del mercado exterior. Por otro lado los principales inconvenientes eran: la insuficiente mano de obra especializada, un trabajo duro a la intemperie, salarios muy altos, necesidad y costos altos de transporte desde el área de producción al lugar de consumo y necesidad de vigilancia en los parques de producción por hallarse éstos en sitios despoblados. A estos inconvenientes previstos, vinieron en la práctica otros más como por ejemplo: otros tipos y clases de material de las cuerdas tanto de las de mantenimiento como de las colectoras; el sistema inadecuado para sujetar a la cuerda la semilla o el mejillón mediano y las condiciones atmosféricas extremas en ciertas épocas del año. Por todo ello McFarlane (New Zealand, 1971) concluye que un método industrial puede desecharse, no por ser malo en sí mismo, sino entre otras cosas por alguna de las siguientes razones: no se ajusta a las condiciones locales, no resulta rentable, no es susceptible a una aplicación inmediata y por la falta de medios técnicos materiales o de personal o, porque, en fin, cree que existe un sistema mejor. Este hombre industrial, ha ideado un nuevo sistema con el complemento de la redecilla especial para envolver el mejillón a la cuerda, sustituyó la mano de obra especializada con lo que podríamos denominar el 'cono McFarlane'. El mismo relata todas sus vicisitudes sufridas hasta consolidar su industria y reconoce haber gastado en 6 años más de US$ 26 000 sin ningún otro beneficio que la experiencia adquirida.

Este es otro ejemplo de la implantación de un sistema de cultivo a costa de la iniciativa privada. En 1972 esperaba tener instaladas 36 bateas de 104 cuerdas cada una (3 744 cuerdas en total). Los dos capítulos de mayor costo, según McFarlane, son: el suministro de semilla, la colocación de los mejillones en cuerdas y la separación de las mismas. No cree que los gastos que ocasiona el 'desdoble' compensen el balance final de la producción.

Ya Andreu (1958) había insistido que el suministro de la semilla es el factor principal para la prosperidad del cultivo.

2.4 *Producción*

La captura mundial de *M. edulis* fue durante los últimos cinco años como signe:

Año	*Producción en toneladas*
1970	269 900
1971	290 900 F
1972	341 300
1973	341 500
1974	288 129 F

Fuente: Annuario Estadístico de Pesca, Vol. 38 (1974), p. 181, F = datos estimados

De esta cantidad el 40 o 45% correspondió a España (el 95% aproximadamente a rías de Galicia de la región Noroeste).

Según Fraga (comunicación personal) la ría de Vigo (España) produce unas 40 000 toneladas de carbono total al año. Esto significa que esta región es capaz de producir unas 70 000 toneladas anuales de carne de mejillón lo que corresponde a unas 181 818 toneladas de peso bruto. Como en la actualidad produce solamente unas 30 000 toneladas de peso bruto la producción de mejillón según Figueras y San Feliu (1972), podría fácilmente quintuplicarse. Fraga (comunicación personal) ha llegado recientemente a la misma conclusión por distinto método.

Según datos recogidos por Gómez Larrañeta (comunicación personal) la producción primaria (expresada como cantidad de carbono asimilado por el fitoplancton mediante la fotosíntesis) por hectárea de superficie acuática durante un año en algunas áreas del mundo es como sigue: 6 toneladas en Perú; 3 toneladas en la ría de Vigo; 1–1,5 toneladas en el Atlántico Norte, 0,2 toneladas en el Mar Mediterráneo.

La producción relativa de especies útiles para el consumo, según el mismo autor, sigue el siguiente orden de valoración: 200 kg/ha/año de anchoveta en el Perú y 186 kg/ha/año de mejillón (bruto) en la ría de Vigo; 80 kg con pesca de arrastre en Islandia; 60 kg en las islas Faroe; 55 kg en las costas de Marruecos; 40 kg en Galicia; 22 kg en Terranova; 17 kg en el Mar del Norte y 10 kg en el Mar Mediterráneo. Las máximas cosechas en las tierras de cultivo en España son del orden entre las 40 y 50 toneladas/ha/año.

Para dar cifras de producción relativa se requiere fijar previamente la superficie total a la cual se refiere la unidad de superficie elegida (la hectárea o el acre). Dicha superficie total puede ser en este caso o bien la superficie de la ría o la superficie ocupada por los polígonos de bateas o la superficie ocupada exclusivamente por las cuerdas colgantes de mejillón.

Así por ejemplo, Andreu (1974) estima la producción de mejillón de la ría de Vigo en unas 60 toneladas/ha/año 'teniendo en cuenta que los parques flotantes están separados por término medio unos 100 metros, por lo que realmente cada uno utiliza alrededor de una hectárea en su casi totalidad gracias a los desplazamientos de los parques en torno al punto de fondeo.

Independientemente de la apreciación expresada por Andreu, ya que el fondeo puede hacerse a una o dos cadenas, y de Ryther (1969) el cual dice que los mejillones como organismos filtradores 'por su capacidad de filtrar el agua traída por las corrientes, es capaz de aprovechar la producción de un ámbito muchísimo mayor que el que en realidad ocupa', nos parece oportuno hacer aclaraciones mediante los datos del Cuadro III, los tres tipos de superficie de producción a los que se pueden referir las cifras de productividad en el caso del mejillón.

Se cree que la superficie más idónea para referir la producción relativa es la ocupada por los polígonos de bateas dado que si dentro de los polígonos de mejillón aumentásemos el número de bateas (o dentro de una batea el número de cuerdas) la producción no aumentaría sensiblemente; mientras que si aumentamos el número de polígonos dentro de la ría, la producción aumentaría según se acaba de decir.

Ryther (1968) atribuye al cultivo del mejillón en postes en Francia una producción de 5 toneladas de carne fresca por ha y año y Waugh (1966) a los cultivos sobre el fondo entre 12 y 25 toneladas/ha/año. Los bivalvos bénticos no sujetos a cultivo producirían unos 150 kg/ha/año de carne fresca. Para el cultivo colgante Ryther (1968, 1969) calcula una producción de 300 toneladas/ha/año de carne fresca.

Hay que admitir que la información manejada por Ryther no es exacta en cuanto a los datos siguientes: emplazamiento de 10 bateas por hectárea y un rendimiento de carne fresca del 50%. Tampoco podía ser exacta la afirmación de que el cultivo colgante del mejillón era de 500 a 1 000 veces superior al de cualquier otro tipo de cultivo sin alimento supletorio.

Hurlburt (1974) recoge dichas cifras de producción con las cuales resulta la producción relativa de España en 20 veces mayor que la de Holanda y 75 veces mayor que la de Francia. Pero si la rebajamos a su valor real (5 veces menor) entonces es solamente 4 veces mayor que la de Holanda y 15 veces mayor que la de Francia.

Según Hickling (1968) la producción de carne de buey en un buen prado de Inglaterra sería de 340 kg/ha/año.

Creemos que en el futuro debería especificarse con claridad sobre todo para el cultivo colgante la naturaleza de la superficie a que referimos nuestros datos, y la clase de peso que calculamos (peso bruto, carne húmeda, carne cocida, desecada, etc.).

En el Cuadro IV se presentan como aclaración a los promedios anuales de los datos aportados por Bardach, Ryther y McLarney (1972) y Hurlburt (1974) los que resultan de los trabajos de Fraga (1956, 1958) sobre el valor nutritivo de la carne fresca del mejillón de la ría de Vigo.

3 Conclusiones y recomendaciones

Las principales conclusiones que se pueden deducir del presente trabajo son las siguientes:

(*i*) de índole biológica: (*a*) Emprender estudios y/o recapitulaciones adicionales sobre la biología del mejillón que abarquen aquellos puntos de mayor interés aplicado al cultivo como por ejemplo, factores ambientales favorables al crecimiento (efecto de la luz, temperatura, producción primaria, *etc*), épocas y condiciones de reproducción más favorables, enfermedades, parásitos, enemigos, *etc* (*b*) Dedicar estudios especiales a los efectos y dinámica evolutiva de los detritos que se acumulan sobre el fondo en un cultivo intensivo de mejillón y su repercusión en la producción de otras especies del bentos. (*c*) Extensión máxima compatible con un policultivo simultáneo con otras especies de interés comercial. (*d*) Unificar criterios para obtener cifras de

CUADRO III

DATOS DE LOS VALORES MEDIOS PARA EL CÁLCULO DE LA PRODUCCIÓN RELATIVA DE MEJILLÓN DE LA RÍA DE VIGO

Dimensiones	
Dimensiones medias de una batea	20 x 20 m
Separación entre cuerdas	0,50 m
Superficie útil del emparrillado de cuerdas	62,5%
Número medio de cuerdas por batea	750
Idem en toda la ría (500 bateas)	375 000
Longitud media de una cuerda	8 m
Separación media entre bateas	100 m
Pesos y rendimiento	
Peso bruto del mejillón comercial por metro de cuerda	12,5 kg
Idem bruto del ejemplar de mejillón comercial (75–80 mm)	0,035 kg
Rendimiento medio anual de carne fresca	38,5%
Rendimiento medio de carne cocida	21,0%
Superficie (ha)	
de una batea	0,04
de las 500 bateas de la ría (C)	20,00
ocupada por los polígonos de bateas (B)	500,00
de toda la ría (A)	16 000,00
Relaciones	
Entre la superficie de la ría (A) y:	
la superficie ocupada por los polígonos de bateas (B)	32
la superficie estrictamente ocupada por las bateas (C)	800
Porcentaje de C con respecto a A	0,125%
Porcentaje de B con respecto a A	3,125%
Producción (toneladas)	
Por batea en 15 meses	75
Anual por batea	60
Anual en toda la ría	30 000

Producción relativa si la producción anual de la ría se reparte entre:

La superficie de producción	*Peso bruto tonelada/ha*	*Carne fresca tonelada/ha*	*Carne cocida tonelada/ha*
A (toda la ría)	1,87	0,72	0,39
B (polígonos)	60,00	23,10	12,60
C (bateas)	1 500,00	577,50	315,00

CUADRO IV

DATOS DE COMPOSICIÓN QUÍMICA Y VALOR NUTRITIVO SEGÚN LOS TRABAJOS DE FRAGA (1956, 1958) Y FRAGA Y LÓPEZ-CAPONT (1958)

Sustancia	%	% *Total*	*kcal*	*kcal Total*
Agua		81,06		—
Proteínas:				
Precipitables por alcohol (1:2)	9,53		38,2	
No precipitables	1,32		5,3	
Total		10,85		43,5
Taurina (aminoácido no asimilable)		0,52		—
Glúcidos:				
Glucógeno	2,36		9,9	
Oligosacáridos superiores	0,11		0,4	
Maltotetraosa	0,09		0,4	
Maltotriosa	0,43		1,7	
Maltosa	0,11		0,4	
Glucosa	0,11		0,4	
Total		3,71		14,2
Mitilita		0,03		—
Lípidos		1,48		13,3
Ácidos orgánicos		0,50		3,0
Cenizas:				
Precipitadas por alcohol	1,35			
No precipitadas por alcohol	1,00			
Total		2,35		—
		100,00		72,97[a]

[a] kcal por 100 g de carne fresca

productividad. (*e*) Divulgar los valores nutritivos referidos al precio unitario del peso de la carne. (*f*) Desarrollar métodos de obtención de semilla (en bancos naturales y en criaderos artificales).

(*ii*) de índole técnica: (*a*) Divulgar a nivel internacional los tres métodos principales de cultivo. (*b*) Determinar relaciones entre la edad, el crecimiento y la textura de la carne (fresca y en conserva). (*c*) Introducir la mecanización en el proceso de cultivo y estudiar sus conveniencias según las condiciones socioeconómicas del área. (*d*) Encontrar materiales adecuados para la construcción de artefactos, cuerdas y demás material empleado. (*e*) Promover el desarrollo tecnológico de los artefactos de cultivo (forma de los flotadores, posibilidades de inmersión de los artefactos para aprovechar las zonas más batidas, sistemas de colocación de la semilla en cuerdas u otro tipo de soportes, *etc*). (*f*)

Mejorar las condiciones del transporte del mejillón vivo y/o envasado según las condiciones climáticas del área.

(*iii*) de tipo administrativo y socioeconómico: (*a*) Analizar la repercusión económica del aumento de la producción. (*b*) Determinar las ventajas e inconvenientes y lograr la protección estatal para el desarrollo del cultivo.

A Hurlburt (1974), después de estudiar diversos sistemas de cultivo de mejillones existentes en Europa para introducirlos en los Estados Unidos le surgieron los siguientes interrogantes casi todos de tipo administrativo:

(*i*) ¿ cuál será la respuesta del mercado a la producción?

(*ii*) ¿ se obtendrá la concesión por la administración central para el uso o disfrute del espacio o del agua necesarios para el cultivo?

(*iii*) ¿ cómo obtener apoyos financieros de tipo estatal para las primeras instalaciones y tanteos a nivel de cultivo piloto?

(*iv*) ¿ cuál es la preparación del cultivador, consumidor y de los escalones intermedios?

(*v*) ¿ cómo realizar estudios de rentabilidad económica?

(*vi*) ¿ cuál es la mecanización del proceso?

(*vii*) ¿ cómo seleccionar el mejor método de cultivo para cada área disponible?

Según Mason (1972), el principal obstáculo para un mayor desarrollo del cultivo de *Mytilus* en el norte de Europa sería la temperatura baja de las aguas y por consiguente el crecimiento lento de los mejillones cultivados.

Como posible instrumento para la solución de los problemas anteriormente reseñados, podría establecerse, bajo los auspicios de la FAO por ejemplo, una Comisión Internacional para el estudio del cultivo del mejillón que se ocupara de: (*a*) la planificación de los estudios e investigaciones de tipo biológico a desarrollar, a la vista de lo realizado hasta la fecha y las necesidades futuras; (*b*) la planificación de los estudios tecnológicos referentes a perfeccionamiento de aparatos, mecanización del proceso de cultivo y la obtención de nuevos productos o aplicaciones; (*c*) la planificación de los estudios administrativos, de economía y rentabilidad, problemas socioeconómicos, de problemas jurídico-administrativos en relación con otros tipos de actividad social, *etc*, y de intercambio entre científicos e industriales de diversas partes del mundo interesados en la materia.

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Economic Aspects of Mussel Farming

P. Korringa

Abstract

Coastal culture of mussels (*Mytilus* spp) is an efficient method of converting marine phytoplankton into nutritious and palatable food. The total world production of mussels is 300 000–400 000 tons (weight in the shell), with Spain and the Netherlands being the leading producers. Increased production is possible although there are several constraints to rapid increases in production.

The economic components for five examples of different systems of mussel farming, including bottom culture (the Netherlands), bouchot culture (France), raft culture (Spain), rack culture (Italy), and a system of submerged collectors (the Philippines) are reviewed. For each system, information is provided on rent, inventory items, expendable items, labour, sales and production.

The cost for each component in different systems varies considerably, depending generally on the degree of mechanisation within the culture system. The costs of labour and raw materials required for culture also affect production costs. The amount of capital required to establish mussel culture is lowest in the Philippines, where considerable potential also exists for increasing mussel production through culture.

Aspects économiques de la mytiliculture

Résumé

La culture côtière des moules (*Mytilus* spp.) est une méthode efficace de conversion du phytoplancton marin en aliment nutritif et sapide. La production mondiale totale de moules se situe entre 300 000 et 400 000 tonnes (poids en coquilles), l'Espagne et les Pays-Bas en étant les principaux producteurs. Il est possible d'accroître cette production encore que son augmentation rapide se heurte à plusieurs contraintes.

Le document passe en revue les composantes économiques de cinq systèmes différents de mytiliculture, y compris la culture à plat (Pays-Bas), la culture sur bouchots (France), la culture sur radeaux (Espagne), la culture sur claies (Italie) et un système de culture sur collecteurs submergés (Philippines). Pour chaque système, l'on donne des renseignements sur les loyers, les stocks, les postes des dépenses, la main-d'œuvre, les ventes et la production.

Le coût de chaque composante varie considérablement d'un système à l'autre, généralement en fonction du degré de mécanisation qu'il suppose. Le coût de la main-d'œuvre et celui des matières premières ont également une incidence sur les coûts de production. Le capital nécessaire à l'établissement d'une exploitation est moindre aux Philippines, où existe également un potentiel considérable d'accroissement de la production des moules de culture.

Aspectos económicos de la cría del mejillón

Extracto

El cultivo de mejillones (*Mytilus* spp.) en las zonas costeras constituye un método eficaz para transformar el fitoplancton marino en alimentos nutritivos y apetitosos. La producción mundial total de mejillones asciende a 300 000–400 000 toneladas (peso con concha). Los principales productores son España y los Países Bajos. Es posible aumentar la producción, aunque son varios los impedimentos a un rápido aumento de la misma.

Se examinan los aspectos económicos de cinco ejemplos de sistemas distintos de cría de mejillón: cultivo sobre el fondo (Países Bajos), cultivo en bouchot (Francia), cultivo en balsas (España), cultivo en bastidores (Italia), y un sistema de colectores sumergidos (Filipinas). A propósito de cada sistema se dan datos sobre alquiler, bienes de existencias, bienes fungibles, mano de obra, ventas y producción.

El costo de cada uno de esos elementos en los diferentes sistemas varía considerablemente, según el grado de mecanización introducido en el cultivo. El costo de la mano de obra y de las materias primas que son necesarias para el cultivo influyen también en los costos de producción. En las Filipinas es donde se requiere menos capital para iniciar el cultivo de mejillones, y las posibilidades de aumentar la producción son considerables.

1 Introduction

Farming of mussels (*Mytilus* spp.) is no doubt the most efficient way to convert the organic matter produced by the marine organisms of the first link of the food chain (phytoplankton and remains thereof) into palatable and nutritious human food. The very short food chain (one link only), the sturdy nature of the mussel, its fast growth, and the rare occurrence of catastrophic mass mortalities caused by parasitic micro-organisms, make it possible to produce large quantities of mussel meat at a very reasonable price.

In efforts to bring larger quantities of animal protein on the market to feed ever increasing human populations, mussel farming is more promising than farming of oysters

and marine fish. The basic requirements are: a reasonable amount of shelter, sea water of good quality, and a fair amount of phytoplankton or remains thereof. These prerequisites are fulfilled in the coastal waters of several countries.

Five different systems of mussel farming are practised, predominantly in Europe: bottom culture (the Netherlands), bouchot culture (France), raft culture (Spain), rack culture (Italy, Yugoslavia) and a system using submerged collectors (the Philippines). These five systems are adapted to the hydrographical, social and economic conditions prevailing in these countries.

The total world production of marketable mussels ranges from 300 000 to 400 000 tons, weighed in the shell. Spain and the Netherlands are the leading producers. Further expansion seems very possible: the common blue mussel (*Mytilus edulis*) is adapted to waters of the temperate zone and can stand prolonged low water temperatures; the closely related Mediterranean mussel (*Mytilus galloprovincialis*) can be grown with success in subtropical waters, whereas the green mussel (*Mytilus smaragdinus*) is adapted to tropical waters. Still, it should be realized that a variety of constraints makes a rapid increase in production unlikely: (*i*) Sheltered areas required to protect the crop, the rack or raft against damage by gales or ice are not available everywhere. (*ii*) Water rich enough in plankton is not always available, and when the water is too rich in nutrients, dinoflagellate blooms may occur which may render the mussels temporarily dangerous for consumption, causing either severe gastro-intestinal disturbances or, in the case of *Gonyaulax* blooms, even paralytic poisoning. (*iii*) Many sheltered areas are so grossly polluted by domestic or industrial wastes that it is not safe to eat molluscan shellfish from these waters, especially so when eaten in the raw state. (*iv*) In some countries, pressure from recreationists makes it impossible to allocate promising sites to mussel farmers. (*v*) Consumer acceptance for mussels differs greatly from country to country. Conservative feeding habits, prejudice against invertebrates as food, the fact that some people are allergic to mussel proteins, and more or less vague religious precepts, make it difficult to market fresh and preserved mussels in many countries. The most striking case is a country like Japan: its people readily consume seafood and are largely dependent on it for animal protein, but mussels are considered as repugnant. It is not easy to alter such attitudes. A spicy preserve like 'escabeche' is more easily accepted than a main dish of stewed mussels; raw mussels to be eaten from the half shell are considered with even greater reluctance.

For the purpose of this review on economic aspects of mussel farming, exact figures are given for one well-selected enterprise for each of the five farming systems, together with the characteristics and limitations of each system. The period for which the figures are valid is indicated. The conversion rates given for local currency to US$ were those in effect at the time the observations were made.

2 Mussel farming (bottom rearing) in the Netherlands

2.1 *General farming techniques*

Mussel farming Dutch-style is a semi-culture, in which the production of mussel seed is completely left to nature. The public seed beds are in principle closed for fishing. Mussels which settle on the natural beds often do not grow there satisfactorily and usually suffer heavy losses from a variety of causes. Transfer to safer and richer grounds is, therefore, the basis of mussel farming in the Netherlands. The Government gives permission to fish on the seed beds during short, well-defined periods. Then the seed is transferred by the farmers to their private growing plots where it is evenly scattered on the bottom. Though the mussel farmer can control certain predators he is faced with a number of risks beyond his control.

As the seed grows the farmer can decide to distribute his mussels over a greater bottom acreage. In due course he will transfer his half-grown mussels to plots where he expects that growth and fattening will be optimal. Natural conditions control the quality and quantity of food in the water flowing over the farming plots. Marketable mussels are fished from the plots and have to undergo a cleansing procedure before they can be offered to the consumer. They can be kept in storage on the cleansing plots in order to serve the market according to demand.

2.2 *Economic aspects*

The following information is generally based on observations of Johannes Zuijdweg and Sons, Yerseke, during the period 1963–72.

2.2.1 *Rents.* One can only become a mussel farmer when one or more culture plots have been leased. The rent to be paid for the plots does not place a heavy burden on the enterprise since it does not fully reflect all the services the Government offers to mussel farmers. The plots in the Waddenzee, measuring 500 × 200 m, nine of which are rented by the firm observed, are leased for a uniform rate of FL 300 per year[1]. The Zeeland plots, however, differ considerably in rent according to their quality. They measure 300 × 150 m and the company has eight of these plots in use. The rents paid by the firm for these Zeeland plots vary from FL 200–900 per plot per year.

2.2.2 *Inventory items.* A well-equipped ship is the most expensive inventory item for the mussel farmer. A good mussel ship (*eg*, a 25 m steel cutter with a 250 hp engine, four power dredges and a hold which can take 50–60 tons of mussels) presently costs about FL 450 000. The hull of the ship has, if properly maintained, a life of 40–50 years. The engine, which has to work at full speed for prolonged periods due to the considerable distance between the farming plots in the Waddenzee and the centre for cleansing, storage and dispatch at Yerseke, has a much shorter life. A new engine is therefore an item which recurs about every 6 years on the budget. The firm has two mussel ships in permanent use; one operating in the Waddenzee and one in Zeeland; the latter ship works both on the farming plots and on the cleansing beds. For maintenance of these two ships, exclusive of amortization, there is an estimated annual expenditure of some FL 50 000. During periods of heavy workload it is necessary for the firm to hire extra ships. For fishing mussel seed this is regularly done at a contract price of FL 4 per 100 kg of seed fished. For one day working on plots in Zeeland, FL 400 is paid per day for ship and crew of three persons.

2.2.3 *Expendable items.* In comparison with inventory

[1] US$ 1·00 = FL 3·23 (6 Nov. 1972)

items, expendable items do not account for a large proportion of the budget of the mussel farmer. Oak sea marks delimiting the plots should be replaced at least once a year. These sea marks are 7–13 m in length, taking the local depth into account, and cost about FL 1 per m. They are placed at 50–60 m intervals. Under heavy duty, the mussel dredges last about two years; replacement of a dredge costs about FL 800. For fishing in deep water the dredge requires about 165 m of steel wire, double galvanized, 10 mm thick with a life of about one year. The ship's engine requires fuel for fishing operations and for voyages to and from the headquarters. One three-day trip from Yerseke to the Waddenzee and back requires about 1 400 l diesel oil. In addition, modest expenses are required for salt to kill starfish, rubber boots and oilskins, forks, shovels and metal baskets.

2.2.4 *Labour.* It is of great importance to have a skilled crew on board the mussel ships. Often, the mussel farmer himself, the leader of the enterprise, will work on board his own ship, but for a large enterprise operating more than one ship, and in the case where one is both mussel farmer and mussel dealer, the director will seldom sail himself. The firm observed, which operates two ships, has six men permanently in service aboard its ships. Wages and social security payments account for at least FL 50 000 per year for a ship with a crew of three. This means that such a ship should land mussels valued at at least FL 100 000 per year to operate on a profitable basis. The number of working hours per week should not deviate too much from those in other enterprises.

2.2.5 *Profitability.* The Dutch Institute for Agricultural Economy has carried out investigations on the profitability of the Dutch mussel industry. Enterprises differentiated into 'small', 'medium' and 'large' categories showed significant differences in profitability with larger firms operating on a much sounder economic basis than smaller enterprises. This is achieved partly through spreading the farming risks in using a greater number of plots in various areas, but above all because the larger firms can make more full-time use of employees and equipment.

One of the greatest problems in this type of mussel farming enterprise is keeping labour fully employed. Renting is advisable only on a daily basis during periodic heavy workload, and not for normal operating conditions. There should be good equilibrium between the number of ships operating, the numerical strength of the crew, and the number of plots worked.

2.2.6 *Prospects of growth in mussel culture.* The basic principle of mussel farming is growing small seed to large consumption mussels on well-protected plots. It is the growing and fattening of mussels which should bring the profit. Mussel farming is a semi-culture, and growth and fattening are to a certain degree governed by the whims of nature. Starting with one ton of small seed, a doubling or tripling of weight can be expected during growth from seed to half-grown mussels (measuring 45–50 mm shell length), but reliance cannot be placed on increasing the tonnage during the growth period from half-grown mussels to mussels of marketable size.

2.2.7 *Production.* The firm Zuijdweg lands some 1 600 000 kg of mussels per year, about 50% from its Waddenzee plots and the other 50% from its plots in Zeeland. The farmers have to deliver their mussels at the auction even if they are also, like Zuijdweg, wholesale dealers. In the 1969–70 season, the price paid at the auction fluctuated between FL 18 and FL 25 per 100 kg of mussels.

2.2.8 *Cleansing and storage.* Since some of the sand and silt swirled up during dredging operations may enter the mantle cavity of the full-grown mussels, a cleansing procedure is necessary. Mussels purchased by the dealer are spread on cleansing plots near Yerseke. Here they are covered with sea water most of the time and get ample opportunity to eliminate any sand or silt. Moreover, they can recover from the fishing stress and transportation and regain enough strength to be transported alive to the markets in Belgium and France.

The cleansing plots serve at the same time as wet storehouses, from which the marketable mussels are carefully dredged up to be guided through a mechanized production line in which they are washed, declustered, graded, and packed in burlap sacks. Therefore the dealers, purchasing mussels at the auction from the farmers, have to sell their marketable product at a higher price, approximately double the price of purchase.

2.3 *Discussion*

Mussel farming Dutch-style in which mussel seed is planted on growing plots and thinned out whenever necessary and transferred to deeper plots, has been practised for more than 100 years. Up to 1950 all the plots for growth and fattening were situated in the Zeeland streams; now 60–70% of the consumption mussels come from plots in the Waddenzee. The industry has kept pace with technical developments, has duly taken into account increase in the costs of labour, and is now mechanized to a high degree. In the first part of the century, the mussel industry stood economically in the shadow of the Dutch oyster industry, but in the post-war period, mussel farming gained in importance and surpassed the oyster industry by developing a high degree of mechanization and by expanding the markets through making use of modern transportation facilities. The rapid technical evolution in Dutch mussel farming should be credited to the imaginative power of the mussel farmers themselves and to their close collaboration with local constructors. Another favourable development was the gradual evolution from a large number of small enterprises to a smaller number of units of greater dimension. Remuneration increases rapidly with the size of the company. There are now about 120 mussel farmers and 12 mussel dealers in the Netherlands, accounting for a total annual production of about 100 000 tons of marketable mussels. Some 15% of the mussels are absorbed by canneries.

Comparison of the Dutch mussel industry with those in Spain and Italy shows that Dutch mussels need more time to reach consumption size. It could be surmised that this difference is due to bottom culture as compared with mid-water farming or to use of water poorer in plankton, but there is no proof for such an assumption. In all probability the difference is brought about by the fact that the Dutch mussels have to winter at temperatures under 10°C for a period of some five months, in which the temperature often drops below 5°C. This slows up the mussels' filtering activity and leads to a serious interruption of growth and fattening.

3 Mussel farming with bouchots in the Pertuis Breton, France

3.1 *General farming techniques*

The origin of mussel farming on bouchots, a typical case of semi-culture, is said to date back to about 1235 in the Bay of Aiguillon. Since then, rows of poles have been placed in the intertidal zone in this area in an effort to collect mussel seed and to grow it to consumption size. Originally, operations were in the very muddy area of the Anse de l'Aiguillon itself, and rows of poles called 'bouchots' served to catch the mussel seed. In a later phase the seed was transferred to bouchots placed somewhat higher in the intertidal zone. These bouchots consisted of rows of poles interwoven with branch-wood which eventually caused silting up of the area to such a degree that operators had to gradually move farther away. For transportation in the muddy area, a small, light, flat-bottomed boat ('acon') was used, but this has given way to transportation of both workers and material by motorboats, making it possible to construct bouchots farther and farther away from the Bay of Aiguillon. The interwoven bouchots are now obsolete, and even officially forbidden to prevent excessive silting and reduce damage from *Mytilicola*. Even seed collecting with poles, practised for ages, has already been replaced to a large extent by collecting seed on coco-fibre ropes stretched out horizontally. Planting poles has been mechanized to a certain extent and long tubes of nylon netting are now used to attach young mussels to the poles of the bouchots where they will grow to marketable size. Despite these recent improvements, the whole system of mussel farming with bouchots is still rather laborious. It is the excellent flavour of the mussels from the region which makes it still possible to compete with the larger production centres in the Netherlands and in Spain.

3.2 *Economic aspects*

This information is based on observations of operations belonging to André Bouyé, mussel farmer at Charron, Charente Maritime in 1971.

3.2.1 *Rents*. The operator has to pay rent for 3 000 m of concession, for the larger part FF 0·20 per running m; for his smaller concession, the minimum rent is FF 50 per concession[1]. A local 'taxe professionnel' (25% of the rental cost) is added to the rent.

3.2.2 *Inventory items*. The most important inventory item is a 13 m wooden motorboat equipped with a diesel engine of 75 hp. The life of the boat is estimated at 15 years, that of the engine 7 years. Special equipment required on board should include a radio-telephone installation, a washing and grading installation with exchangeable trellis, a weighing machine used in filling the sacks, and a 3 hp pump with petrol engine. For proper maintenance the boat should be treated with submarine paint 4–5 times per year, which requires 1–2 days of work each time. The motorboat tows a 6 m wooden 'yawl' equipped with a 4 hp outboard engine. The yawl has an estimated life of 6 years. On board, the motorboat also carries two light-weight wooden 'acons' 3·10 m long, with a life of 5 years. For storage of modest quantities of consumption mussels, the company uses 2 wooden racks carrying wooden cages strung with metal wire netting. The wood has a life of 5 years, but the wire netting should be replaced every year. Ashore, a truck with a carrying capacity of 500 kg and an estimated life of 4 years is used for local transport of poles and personnel, as well as for transporting material to the Bay of St. Brieuc, on Brittany's north coast, where the operator observed has auxiliary parks. Small tools such as scrape-nets, scrapers and shovels used on board are not included in the inventory list.

3.2.3 *Expendable items*. The poles of the bouchots last five or six years. Therefore regular purchase of oak poles of 4 to 6 m length, costing FF 8 each, is a necessity. The operator has 3 000 m of concession, partly used for production of mussel seed (130 poles per 50 m) and partly for growing consumption mussels (84 poles per 50 m). The poles are bought from farmers or timber merchants in the area. The total number of poles the company has in the field represents an appreciable capital. For procuring seed with coco-rope, 100 m of concession is used which requires an annual purchase of 5 000 m of 1 cm diameter rope, costing FF 0·15–0·20 per m if purchased directly from a wholesaler in Marseille.

In addition, it is necessary to purchase cylindrical nylon netting to transfer the seed to the poles used for producing marketable mussels; 10 m of netting is required for each pole of the growing area. The netting lasts about one year and costs FF 1 per m. Since the operator requires some 4 000 poles for growth and fattening, some 40 000 m of netting has to be purchased each year.

For packing consumption mussels it is necessary to purchase non-returnable sacks of woven plastic or of burlap. Some 4 000 sacks are needed if the operator ships all the mussels in sacks; in fact, some are shipped in plastic baskets which are repeatedly used. Further, the company has to purchase oil for the 75 hp diesel engine of the boat. The boat is used almost every day; the trip takes one hour to the nearest bouchot, but two hours for those far away from the home port. When at the working area petrol is needed for the outboard engine and for the pump on board used for placing poles and washing consumption mussels. Less important are the annual expenses for some 100 kg of iron nails, submarine paint for maintenance of the fleet, and rubber gloves.

3.2.4 *Production*. Since the mussel seed is not bought but procured with seed-bouchots or coco-fibre ropes, there are no records as to how much mussel seed is transferred to the growing and fattening bouchots. If all seed were placed in nylon netting if would be possible to make a rough estimate as the nets have a diameter of some 10 cm and a length of 2 × 5 m per pole, but for the seed collected with ropes it is more difficult to estimate the quantity. The operator expects to harvest on average 25 kg of marketable mussels each year from every pole used for growth and fattening. This agrees well with the fact that he uses about 4 000 poles and produces some 100 tons of consumption mussels per year.

3.2.5 *Personnel*. The operator works full-time in the field, always assisted by one man. In times of heavy workload, such as building a new bouchot or making a rack for rope-farming, assistance is requested from another mussel farmer. Administration is handled, but not paid for, by family members.

[1] US$ 1·00=FF 5·035 (6 Nov. 1972)

3.2.6 *Sales.* Some 100 tons of marketable mussels are produced annually from this operator's bouchots in the area under consideration. It should be noted that a further 50 tons is produced on another 1 200 m of concession in the Baie de St. Brieuc on the north coast of Brittany. Workers are hired often during the period 15 February to 15 April. The price the farmers will receive for consumption mussels is fixed by a syndicate in the month of March. In 1971, the price paid for regular quality mussels packed in sacks ('départ logé') was FF 1·35/kg.

3.2.7 *Further development.* The operator is not planning to increase the production of mussels for the time being. There is no lack of mussel seed; if so desired, it could be easily increased by using a greater length of coco-fibre rope. Lack of personnel is not a limiting factor either. Shortage of high quality concessions for rapid growth and fattening of consumption mussels is the real bottleneck for the company. It is an economic disadvantage that the company's concessions east of the River Lay are so heavily divided. Reallotment would certainly be advantageous to the firm. The market for small-size consumption mussels does not seem to be very elastic, especially at the beginning of the season when the mussels can only be transported over rather short distances.

3.3 *Discussion*

Mussel farming with the aid of bouchots, a system of semi-farming with a very long tradition, has escaped the danger of 'involution'. There has been no hesitation in introducing new methods and modern equipment to keep pace with changing situations. Still, this system of mussel farming is quite laborious and it is not expected that this industry will increase significantly in the area. Silting up of the Anse de l'Aiguillon, to which the mussel farming operations have certainly contributed, has made it necessary to gradually build the bouchots farther and farther away. Introduction of motorized vessels has supported this action. The mussels do not reach a large size here, presumably because of farming in the inter-tidal zone and because of physiological interference by excessive amounts of inert suspended matter. The minimum legal size is remarkably low (4 cm, formerly 5 cm), but the meats are usually plump and of extraordinarily good flavour. Therefore the regional markets readily absorb these mussels.

The total length of all bouchots in the Aiguillon-La Rochelle area amounts to some 600 km, with an annual production of 7 000 tons of consumption mussels. The total mussel production in France amounts to some 45 000 tons. Hanging culture systems in the Etang de Thau, similar to mussel farming in Italy, are the leading producers with 10 000 tons. Another 10 000 tons are fished from natural beds.

4 Mussel rafts in Galicia, Spain

4.1 *General farming techniques*

Mussel farming Spanish-style is a semi-culture in which the first phase of the mussel's life-cycle, *ie*, larval development, is left completely to nature. The mussel seed settles freely on rocks, especially in the intertidal zone, but also during part of the year on ropes hung especially for that purpose from floating mussel parks. The mussel seed is collected by hand from the rocks to be transferred to ropes, which are hung from specially constructed mussel rafts. The seed which settled directly on ropes is in due course distributed over more ropes and then hung again from the rafts. Rafts have to be used here since the rías (sunken river beds in coastal regions) are deep and have a muddy bottom.

Hydrographical conditions prevailing in the rías of Galicia account for the production of dense phytoplankton which makes the mussels, permanently bathed in sea water, grow rapidly. When the total weight of mussels on a given rope exceeds a certain limit, the ropes are taken up and the mussels distributed over a greater length of rope. When the mussels have attained marketable size they are detached from the rope and either sold to canneries or placed in a purification basin to provide markets in the interior and abroad with mussels of a high standard of cleanliness.

4.2 *Economic aspects*

This information is based on the operation of Industrias Marítimo Pesqueras (Proprietor-Director—Don Luis Losada Lago), Punta Preguntioro (Villajuán), Villagarcía de Arosa, which was observed in 1970–71.

4.2.1 *Rents.* Spanish mussel farmers need not pay rent for mooring their floating parks in the rías.

4.2.2 *Inventory items.* The company under consideration operates with six floating parks for mussel farming, one being a sturdy old wooden boat with a system of outriggers, very convenient for an exposed site, and the other five being large rafts of a catamaran-type carrying some 1 000 ropes. It costs Pts. 500 000 to build such a catamaran-park whereas the regular type of park with four floats, carrying 600–700 ropes, costs Pts. 300 000[1]. A well-constructed raft has a life of several decades.

Another important inventory item is a motorboat. Such a boat, equipped with a 24 hp diesel engine, costs about Pts. 250 000 and has a life of some 20 years. Since no heavy duty such as dredging has to be done, the engine also has a long life. The powered crane on the bow used for taking up ropes coated with mussels costs about Pts. 50 000.

The investment in purification and storage basins of the company under consideration are out of proportion to the mussels farmed by the enterprise itself as the company ships about 20 times the quantity of mussels it produces with its own parks. Size and construction of the shore plant (1 200 m^2 of outdoor basins, 800 m^2 of indoor basins with two 50 hp electric pumps of a capacity of 700 m^3/hour, complete with pipelines, shed, workshop and laboratory) give some idea of the magnitude of such an investment. Some equipment that would be necessary for a smaller plant includes: a wagon with pneumatic tyres (Pts. 15 000) for dragging containers with mussels from the quay to the shed with a 10 hp electromotor (Pts. 20 000) and a 50 m steel cable 12 mm thick. The plastic baskets, holding 17 kg of mussels and used in the storage basins, cost Pts. 160 each, and iron baskets Pts. 100.

4.2.3 *Expendable items.* Purchase of ropes is an ever-present item on the budget of the Spanish mussel farmer. Rope made of synthetic fibres such as that used by the company under consideration costs some Pts. 50 per kg (about 8 m) and though it has a life of many years, it should

[1] US$ 1·00 = Pts. 63·5 (6 Nov. 1972)

be replaced occasionally. Each catamaran-raft carries 1 000 ropes of 6–9 m length. A further item is a specially made tissue, which costs Pts. 25 per roll of 200 m, sufficient to coat 6–8 ropes with mussels. It is used once only during the period the mussels are left on the rope (3–6 months for seed to half-grown mussels, 8–12 months for the growth period from half-grown size to consumption size). Sometimes a third lot of tissue is required when extra thinning out is deemed necessary.

The company buys about half the seed it needs. About 100 boxes (40 kg) of seed, purchased at a price of about Pts. 3·50/kg, are required to adequately coat the ropes attached to one catamaran-raft.

Expenditures should also be allowed for fuel and lubricating oil for the motorboat; maintenance of ships and engines; electricity for lights, for electromotors and pumps; and sacks for packing the mussels (Pts. 4·50 for a gauze sack carrying 15 kg of mussels).

4.2.4 *Labour and personnel.* The company under consideration employs 15 male labourers full-time throughout the year for farming, storage and shipment of mussels; up to 40 female workers are employed in the winter season and about 20 in summer. The wages are in the order of Pts. 250–350 per day. The men do the work at sea, while the women stay ashore. The work involves coating the ropes with mussels, transferring mussels to longer ropes, sailing to and from the floating parks, and harvesting ropes with marketable mussels. Cleaning and grading are the most time-consuming operations.

Special mention should be made of a pharmacist-bacteriologist hired for six hours each day to ensure sanitary conditions of the mussels.

4.2.5 *Purchase and sale of consumption mussels.* The company buys large quantities of consumption mussels from other farmers, in fact the total production of some 200 parks. The purchased mussels still have to be cleaned, graded, purified and stored. The price to be paid, up to Pts. 5/kg, depends not only on size and quality, but also on the actual price on the markets of Spain. The company sells about 3 000 tons of mussels per year, 80% for exportation and 20% for markets in the interior. The price of export mussels is Pts. 8/kg packed in sacks and carriage paid to the border. Cost for transport in a regular truck to the border town of Irun is Pts. 1/kg and Pts. 1·30 for isothermic transportation.

4.2.6 *Further development.* Considering that the company buys far more marketable mussels than it produces with its own floating parks, it could be that it is more economical to buy marketable mussels from small private farmers—who do not count their hours—than to produce mussels with hired hands. This assumption may not be correct as the company has applied to construct six more parks of its own.

It cannot be denied that mussel farming Spanish-style requires a considerable amount of manual labour and that mechanization has not been incorporated to any significant degree. Therefore, the price of labour determines to a very great extent the production costs for consumption mussels. The price for export mussels has not changed appreciably in recent years and, since one has to take into account the price paid for mussels produced in France, the Netherlands and Italy, it cannot be expected that the price received in Spain would be more than Pts. 7/kg plus freight to the border.

4.3 *Discussion*

Mussel farming in Galicia is a striking example of rational exploitation of a natural resource which yielded nothing until man intervened. Early in the century, a system of mussel farming on racks on the Mediterranean coast was developed, especially in the areas of Tarragona and Barcelona, based on the old Italian system of mussel farming. Then the first floating mussel park was built in 1946 in the Ría de Arosa, closely followed by another in the Ría de Vigo, and this led to a rapid development of the Galician mussel industry. Fortunately, it was possible at the same time to develop a market for mussels in parts of Spain where mussels were otherwise not known. Initially only old barges were used for the construction of mussel parks, but in the early fifties mussel culturists started to construct special mussel rafts. Gradually both materials and methods were improved. Ropes of esparto grass have been replaced almost completely by ropes of synthetic material. The specially developed crane at the bow of the mussel boats recently made the long masts on the rafts superfluous and eliminated heavy labour. The work which was originally carried out on board the rafts, predominantly by female labourers, even in bad weather, is now largely being carried out in sheds on shore, at least in the Arosa area.

Since mussels destined for export should be trained to keep their valves tightly closed during transportation, they are repeatedly exposed to air during one or two weeks. Formerly this was done by simply putting them on the beach, which involves serious risks in warm weather, but there are now at least 12 storage basins for this purpose in the Galicia area.

The total mussel production from the over 3 000 parks in Galicia is somewhere between 140 and 160 million kg of marketable mussels. Of this, roughly 10% is exported, especially to France and to Italy, about 50% is brought in fresh to the markets of the interior, whereas some 35 to 40% goes to the mussel canneries, which make the famous 'escabeche'. Some of the canned mussels are exported, for example to the Federal Republic of Germany.

The possibility of further mechanization, the price of labour in Galicia, and the further development of the markets at home and abroad will be the main factors governing the future of the Galician mussel industry.

5 Mussel farming on racks in La Spezia, Italy

5.1 *General farming techniques*

Mussel farming Italian-style is a semi-culture in which both larval development and the provision of food for juvenile and adult mussels are fully left to nature. Though the mussel farmers do use mussel seed which settles naturally on rocks and other solid substrates as primary material, by far the largest part of the seed requirement is procured with the aid of artificial collectors.

Characteristic of the Mediterranean Sea is the very low tidal range and hence the prevailing low current velocities. In the sheltered areas where mussel farming is practised the bottom is predominantly soft and muddy, and the mussels must be grown off the bottom. For this, the Italian mussel farmer constructs mussel parks comprising networks of poles connected with horizontal ropes. From these ropes

they hang their strings of mussels which are permanently bathed in sea water and do not touch the muddy bottom. A special type of rope is stretched around the parks to collect the seed. To control fouling organisms the strings of mussels are exposed for some time to air whenever necessary.

Most of the actual work is done at sea. The marketable mussels are cleaned and graded and sold on strings or neatly separated and packed for local consumption.

5.2 *Economic aspects*

This information is based on observations made in 1971–72 of Cooperativa La Proletaria, Viale S. Bartolomeo 525, La Spezia.

5.2.1 *Rents.* The Italian Government promotes exploitation of mussel parks by co-operatives by granting them very favourable leasing terms; in the case of the firm under consideration, an annual rent of Lit. 5 000[1] is charged. The co-operative, consisting of 18 participant-proprietors has at its disposal 31 plots with a total surface of 2·7 ha.

5.2.2 *Inventory items.* The co-operative, La Proletaria, operates with 8 motorboats, 18 working boats and 2 smaller boats called 'gozzetto'. Five outboard engines are kept in stock to be mounted on the working boats when there is no motorboat available. A motorboat, as used by the mussel farmers of La Spezia, can be purchased for about Lit. 700 000 and a suitable (12–15 hp) engine costs about Lit. 800 000. It may have a life of up to 25 years, but after about 15 years considerable repair work may be needed. The engine may also last 25 years, but with the new and better types of engines on the market it is likely that old engines will be replaced sooner. Maintenance costs for the boat would be about Lit. 50 000 per year, which includes painting twice a year.

The wooden working boats cost about Lit. 700 000 each. If properly maintained they will last at least 20 years, and annual maintenance costs are in the same order of magnitude as for the motorboats. A 7 hp outboard engine can be purchased for Lit. 400 000 and has a life of about 4 years.

The annual fuel expenses per 1 000 m^2 of park include Lit. 54 000 for fuel for outboard engines (average use made: 2 hours per day during 25 days per month), Lit. 10 000 for diesel oil for the motorboat and Lit. 10 000 for motor pump fuel.

Other inventory items are the motor pumps to be used on board to wash the mussels, which cost Lit. 60 000 and have a life of 4 years. On shore the following items are needed: a derrick on the wharf, to hoist boats and engines, costing Lit. 250 000 with an estimated life of 25 years; welding apparatus to make iron poles of the desired length, costing about Lit. 200 000 with a life of 20 years; a pump for washing consumption mussels, costing Lit. 700 000 with a life of 12 years; a weighing machine with a capacity of 100 kg, costing Lit. 300 000 with a life of four years; a non-automatic balance of Lit. 50 000 which lasts eight years; a ladder to load the sacks with mussels on the trucks for Lit. 500 000, life 15 years; and a 5 m long barrow on two pneumatic tyres to transport poles to the boat.

A landing stage, and a shed to store various materials is also required. There is an office for administration.

5.2.3 *Expendable items.* Purchase of wooden or iron poles is a recurrent item on the budget of the Italian mussel farmer. To construct a standard park of 1 000 m^2, 116 poles are required of different lengths from 13–15 m for sites 8–9 m deep, and from 16–18 m for places where the depth is 11–12 m. One pole of chestnut wood costs about Lit. 6 000; they last two years only. The co-operative under consideration now uses iron poles almost exclusively (92%) which cost more than double the price (Lit. 14 000) but will last five years and hence require less labour for replacement. For 90% of its operation, the co-operative uses pipes of plain iron (76 mm diameter, wall 3·75 mm thick) costing Lit. 1 000/m, but experiments are being conducted with galvanized iron pipes costing Lit. 1 200/m and pipes coated with a mixture of bitumen and glass wool (Lit 1 200/m) which are said to last for at least seven years.

Parks constructed in deeper places have higher costs for poles than in shallow areas but the greater length of the mussel strings compensates to some extent for the higher costs.

For the construction of the parks, another item required is polyethylene rope, 14 mm thick. For a standard park of 1 000 m^2, 1 900 m of rope is needed at a cost of Lit. 160/m, and should be replaced every 3–4 years. In addition, 275 m of a thicker rope is needed for collecting mussel seed, and lengths of 8 mm polyethylene rope to tie the poles together at the periphery of the park, and to suspend the collecting rope from the oblique poles.

A further item required is the cylindrical netting which contains the strings of mussels. A park of 1 000 m^2 carries some 720 strings measuring 4–8 m. First the seed is put in rather fine-meshed netting (Number 14 mesh). It is transferred a couple of months later to Number 12 mesh netting, and often it is necessary within the same year to transfer the mussels to Number 10 mesh. Therefore, allowance should be made each year to purchase 8–16 000 m of 'Netlon' at a cost of Lit. 6·50/m for every 1 000 m^2 of park.

Packing material (boxes or sacks) is estimated at Lit. 5/kg of mussels, and electricity ashore, *eg*, for illumination, for welding and for operating pumps and ladder is obtained at moderate cost.

5.2.4 *Labour.* The mussel farming technique in this area requires a considerable amount of manual labour. Apart from the use of engines and motor pumps in the boats, very little has changed in the labour pattern in the course of this century. The main jobs to be done are: welding poles together to the desired length; constructing parks with poles and ropes; replacing poles and ropes occasionally; collecting mussel seed; making strings from the seed by packing it in cylindrical netting and hanging them in the parks; transferring half-grown mussels to a greater length of netting; hanging the strings repeatedly in the air; transferring strings from polluted parks to clean parks; harvesting the strings carrying consumption mussels and cleaning, grading, washing and packing the mussels for sale.

It is difficult to separate the exact number of working hours required for each of those items but in general one may assume that one experienced mussel farmer can operate a park of 1 000 m^2. The co-operative La Proletaria, which comprises 18 participant-proprietors exploiting 27 000 m^2 of parks, also employs 4 hired workers the year round at a cost of Lit. 175 000 per month including taxes and recruits approximately 40 man-days of labour during

[1] US$ 1·00 = Lit. 584·5 (6 Nov. 1972)

periods of high workload for a total annual cost of Lit. 200 000. A watchman is also employed at a rate of Lit. 58 000 per month.

5.2.5 *Sales.* The price for which the consumption mussels are sold to the wholesalers amounts to Lit. 115/kg for mussels packed in sacks and boxes, and Lit. 80 for mussels in bulk, *ie*, the complete string. The retail price is about Lit. 250. The total production of marketable mussels fluctuates somewhat from year to year. The co-operative La Proletaria sold about 570 tons of mussels in the year 1968 and 450 tons in 1970. The total annual production of mussels in Italy amounts to some 30 000 tons. During the last few years, all the mussels produced could not be sold, partly because of severe competition by importation of Spanish mussels which are of larger size (8–9 cm against 6–7 cm for the mussels of La Spezia) and often have a better meat content, especially in the winter months. Therefore, the Spanish mussels can be sold to the wholesalers at Lit. 200–250/kg, who in turn sell them retail for Lit. 400/kg.

5.2.6 *Losses.* It is estimated that annual losses due to damage to parks by gales in La Spezia amount to 5%. Theft is a rare occurrence since paid watchmen survey the area.

5.3 *Discussion*

Mussel farming as carried out in La Spezia is an excellent example of rational exploitation of a body of sea water rich in phytoplankton. The perfect shelter offered by the western peninsula makes it possible to construct mussel parks at rather low costs. The percentage of loss of mussels during the farming procedure is exceptionally low.

Reasons for concern for this industry include: the very low degree of mechanization; the large number of man-days required to produce one ton of marketable mussels; the rather scanty gross income per participant-proprietor of the co-operatives; the difficulty of attracting young farmers to take over from the older ones in the co-operative; the increasing pollution of the water, which leads to greater expenses in constructing parks in deeper sites further away from the headquarters, extra costs for bringing marketable mussels to pure water, and presumably higher incidence of encrusting organisms on the shell of the mussels.

When the increasing competition by imported Spanish mussels is added to these factors, it must concluded that the future of mussel farming in La Spezia is not very bright.

6 Farming the green mussel on submerged collectors in the Philippines

6.1 *General farming techniques*

Farms for molluscan shellfish are predominantly located in the temperate zone of the northern hemisphere and in subtropical areas, but rarely in the tropics. The Philippines form a noticeable exception to this; many oyster farms are operated there and mussel farming has been taken up recently. Molluscan shellfish, rich in protein, have been a very valuable addition to the diet of the dense population of these islands.

The green mussel (*Mytilus smaragdinus*), locally called 'tahong', is farmed sub-tidally in sheltered sites. To collect the mussel seed, extensive bamboo structures are erected in places with a rather muddy bottom. A good settlement of mussels is anticipated where acorn barnacles (balanids) have settled in fair numbers on the bamboo well under the low water mark. The mussel farmers in Bacoor Bay do not transplant or thin out their mussels, but keep them on the bamboo supports until they reach marketable size, roughly six months after settling. The mussels are harvested by divers, who pull the poles carrying the mussels out of the mud and strip them clean on board a boat. Well-graded and cleaned, the mussels are transported rapidly to the market where they are sold while still alive.

Based on experience gained in oyster farming, several systems of park construction were devised, but it was found that a rather open construction is to be preferred because of greater strength and better growth and fattening of the mussels. Formerly, the so-called 'wigwam' method was practised on quite a large scale, in which eight long bamboo poles were placed in a circle 4 m in diameter around a central pole and nailed together with short horizontal bamboo braces just above the low water mark. Slender bamboo poles were then placed inside the frame, using the central pole as the pivot. However, the 'wigwam' method may easily lead to overcrowding and poor growth, and breakage of one pole may easily lead to collapse of the whole structure. Therefore virtually all the Bacoor Bay mussel farmers, including the firm chosen as the example, now practise the 'stage' system, characterized by rectangular bamboo structures.

Since mussel farming Philippine-style has only two labour peaks, *ie*, for building the bamboo structure and for harvesting the crop, the underwater work is carried out mostly by divers hired for this purpose.

Most of the farmers work on a small area of 0·25 ha, which may yield some 2 500 gal (about 6 500 kg) of mussels in the shell per year.

6.2 *Economic aspects*

This information is based on the tahong farm of Mr. M. Alagar, Barrio Siniguelasan Bacoor, Cavite, Luzon in 1971–72.

6.2.1 *Rents.* For a park of 0·25 ha a municipal tax of PPs. 18 is paid per year[1].

6.2.2 *Inventory items.* The mussel farmers of Bacoor Bay usually have their own boat, called a 'banca', a simple dug-out canoe 7–10 m in length and 40–60 cm width, with a wooden framework covered with waterproof plywood to increase the height. These boats are usually equipped with an inboard gasoline engine of 1·5–12 hp. The boats have quite a long life and are rather inexpensive. A boat of 10 × 0·5 m costs PPs. 2 000, whereas a Briggs & Stratton or 'Wisconsin' 9 hp motor also costs about PPs. 2 000.

Wharf space is needed for the boat. The only tools needed are some scrapers, knives and rattan baskets.

6.2.3 *Expendable items.* Every year the mussel farmer has to purchase bamboo stakes. For the farm under consideration, 5 000 stakes are needed for 0·25 ha farming area and each stake lasts about one year. The stakes, 4–6 m long, are purchased from dealers at PPs 0·20 each. Farmers operating on deeper plots have to buy longer bamboo stakes (8–10 m long, 10 cm in diameter at the butt end) for a higher price (PPs. 1·20 each) but these will last up to two years.

[1] US$ 1·00 = PPs. 6·70 (6 Nov. 1972)

The farmer needs gasoline for the engine of his boat. Since the distance from the wharf to the park is only about 3 km and frequent visits are only necessary at the time the stakes are put out and when the mussels are harvested, this item does not weigh heavily on the budget of the farmer.

6.2.4 *Personnel and wages*. The mussel farmer considered has no personnel in permanent employment. When the stakes have to be put out in the park he contracts a group of divers, usually five in number. This group can place 1 000 stakes in 2–3 hours. The wage prevailing at the time of observation was PPs. 50 per 1 000 stakes. The whole 0·25 ha park holds about 5 000 stakes.

At the time of harvesting the farmer again hires a group of workers for diving to pull out the stakes covered with mussels, for scraping the mussels off, and for grading and cleaning them on board the boat. Five male workers can gather 500 gal of mussels in 2–3 hours when the poles are well covered. They are paid PPs. 0·30–0·40 per gal of mussels collected.

6.2.5 *Production and sales*. The production may fluctuate rather widely according to the quantity of mussels per running metre of pole, and to the length of the poles used. Poles of the type used in the farm under consideration may each carry 2 gal of mussels in the shell weighing about 5 kg.

A total production of 5 000 gal per year per 0·25 ha park is considered as normal.

The price paid for the mussels varied at the time of observation from PPs. 1·50–2·00 per gal. On the retail market, consumers pay PPs. 0·50–1·00 more per gal.

6.3 *Discussion*

Based on the experience of oyster farmers, a mussel farming industry has been created in recent years with the assistance of the Philippines Fisheries Commission. The capital required to start a 0·25 ha farm is small, in the order of a few thousand Pesos, so that a reasonable living can be made by farming mussels. The different varieties of bamboo required for material are readily available at a low price, and workers to be contracted as divers for a few days are easily located in the densely populated sections of the Philippines. There is considerable potential for production and marketing of green mussels in the Philippines which would contribute materially to the food value of the diet of the local population.

7 Reference

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Settlement and Survival of Giant Scallop, *Placopecten magellanicus*, Larvae on Enclosed Polyethylene Film Collectors

K. S. Naidu, R. Scaplen

Abstract

A method of collecting wild giant scallop, *Placopecten magellanicus*, spat using polyethylene film near Newfoundland, Canada is described. Total spat settlement increased with depth to about 12 m after which a decrease occurred. Collectors suspended shallower than 8 m were found to contain few live spat but harboured considerable numbers of starfish, the frequency of which decreased with depth down to about 12 m. Starfish (*Asterias vulgaris*) predation is thought to be the most important factor influencing numbers of live spat in the upper collecting units.

Fixation et survie des larves de coquilles St-Jacques, *Placopecten magellanicus*, sur des collecteurs entourés d'une pellicule de polyéthylène

Résumé

On décrit une méthode pratiquée à proximité de Terre-Neuve (Canada), pour recueillir du naissain de coquilles St-Jacques, *Placopecten magellanicus*, en utilisant une pellicule de polyéthylène. La fixation totale de naissain augmente avec la profondeur jusqu'à une douzaine de mètres, niveau en deçà duquel elle décroît. Les collecteurs suspendus à moins de 8 mètres contenaient peu de naissain vivant mais, en revanche, de grands nombres d'étoiles de mer, dont la présence diminuait avec la profondeur jusqu'à environ 12 mètres. Il semblerait que la prédation exercée par les étoiles de mer (*Asterias vulgaris*) soit le facteur le plus important de survie du naissain dans les collecteurs supérieurs.

Fijación y supervivencia de larvas de vieira gigante, *Placopecten magellanicus*, en colectores de película de polietileno

Extracto

Se describe el método utilizado cerca de Terranova (Canadá) para la fijación de larvas de vieira gigante, *Placopecten magellanicus*, utilizando película de polietileno. La fijación total de larvas aumenta con la profundidad hasta llegar a los 12 m, a partir de los cuales disminuye. En los colectores suspendidos en aguas menos profundas de 8 m se encontraron pocas larvas vivas y un número considerable de estrellas de mar, cuya frecuencia disminuye con la profundidad hasta llegar a los 12 m. Se cree que la actividad depredadora de las estrellas de mar (*Asterias vulgaris*) es el principal factor determinante del menor número de larvas vivas en los colectores que se encuentran en las capas superiores del agua.

1 Introduction

There is little published information on the culture of North American pectinids, except on methods of inducing adults to spawn and descriptions of larval development (Sastry, 1965; Costello *et al*, 1973; Culliney, 1974). Much of the pioneering work on scallop culture has been conducted in Japan, where the use of spat collected from wild populations using various artificial substrates is favoured. In North America the tendency has been to use laboratory-raised animals as sources of spat (Castagna and Duggan, 1971; Duggan, 1973; Castagna, 1975). Techniques relating to the culture of commercially important North American species, such as the giant scallop (*Placopecten magellanicus*) are presently being investigated.

The giant scallop ranges from the north shore of the Gulf of St. Lawrence to Cape Hatteras, North Carolina (Posgay, 1957). It usually occurs in depths from 15 to 110 m, or in shallower waters in the northern portion of the range. As annual recruitment of this species is highly variable (Dickie, 1955; Naidu, 1975), and regeneration of natural beds relatively slow, the Newfoundland Department of Fisheries decided in 1971 to investigate the feasibility of resource enhancement for this species.

Several artificial substrates have been tested for economic suitability and collection efficiency. These include nylon netting, burlap, fibreglass, and polyethylene film (Evans, Scaplen and Idler, 1973). To date, polyethylene

film appears to be the most suitable. Japanese workers have used this substrate in the collection of *Patinopecten (Mizuhopecten) yessoensis* seed. A smooth substrate facilitates rapid removal of scallop spat.

Spatfall has been monitored at various locations in Newfoundland for the past three breeding seasons; it normally occurs in enclosed bays between late September and November, depending on water temperatures. These studies indicated that the best areas for collection are those where plankton counts (numbers/l) are consistently high and polymorphic in species composition (Scaplen and Idler, 1974). Methods for inducing spawning in adults and the artificial rearing of larvae to settlement stage have also been examined (Evans, Scaplen and Idler, 1973; Scaplen and Idler, 1975). While larvae may be brought up to the pediveliger stage, settlement has not been achieved in mass culture (F. Walsh, personal communication).

The Burin Peninsula was selected as a promising site for scallop farming and the Newfoundland Provincial Government expanded the project into a pilot commercial-scale operation (Clugston, 1974). Two sites were selected for spat collection. This paper discusses the large-scale spat-collecting technique used at one of these sites and examines some problems relating to settlement and survival on artificial substrates. An attempt is also made to identify possible modifications for experimental collecting devices to optimize settlement and survival of seed scallops.

2 Materials and methods

Ten spat-collecting devices were set out in Little Bay Mortier (47° 10′N, 55°06′W) in early August 1974. Each consisted of a main rope 200 m long from which 20 branch ropes spaced at 2·5 m intervals were strung. Each branch rope was 15 m long and carried 20 spat collectors spaced at 60 cm intervals. The first collector was attached to the branch line about 2 m from the surface. Each spat-collecting unit consisted of a bag (75 × 42 cm) of 1·5 mm mesh containing 3 sheets of polyethylene (Hizex[1] film), each of approximately 52 × 24 cm. A total of 4 000 such units were used. The main rope with six floats was moored by two anchor ropes and held taut by use of sandbags. The spat-collecting units were lowered during the winter months so that the buoys were submerged to avoid damage or gear loss by ice.

From 3 to 5 June 1975, all branch lines were removed and counts made separately of the numbers of live scallop spat, dead spat and starfish (*Asterias vulgaris*) in each bag from six branch ropes. SCUBA divers ensured that all branch ropes sampled were freely suspended in the water column. Some of the lower units which had been in contact with the sea bottom were not included in the samples. To minimize mortality of the young animals, photographs were taken of the spat retrieved from each bag and measurements made from these photographs with vernier calipers.

3 Results

Mean scallop settlement (both live and dead spat) per bag increased significantly with depth down to about 12 m ($r=0{\cdot}836$, $df=18$, $P<0{\cdot}01$); deeper than this, the numbers settling showed some decrease (Fig. 1). Collecting bags near the end of branch ropes were observed to carry more silt than those held at shallower depths.

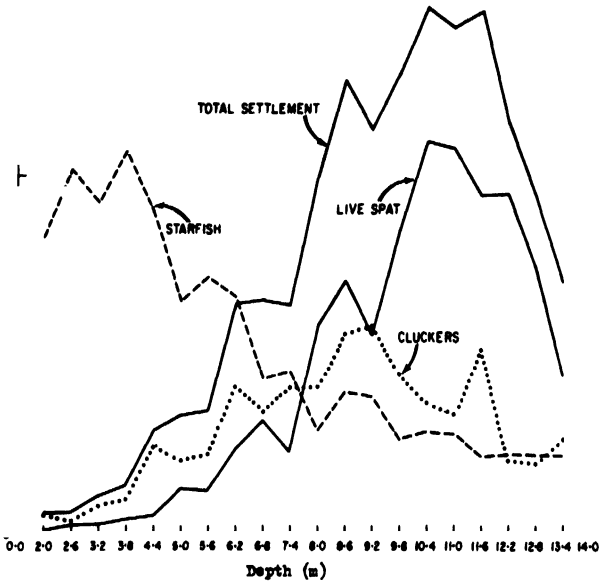


Fig 1. Variation in mean numbers of live scallop spat, cluckers, total scallop settlement, and starfish with depth

The mean number of live spat per bag also increased with depth ($r=0{\cdot}772$, $df=18$, $P<0{\cdot}01$), the last 10 of the 20 bags accounting for 86% of the total collected. Bags suspended in less than 8 m depth contained fewer live spat, but harboured considerable numbers of starfish. Live spat numbers and starfish were significantly correlated ($r=-0{\cdot}933$, $df=18$, $P<0{\cdot}01$). On the average there were three times as many cluckers (dead animals with both valves still attached) as live spat in the first five bags; the converse was true for the last five bags.

The mean size of live scallop spat (dorso-ventral axis) was $12{\cdot}4 \pm 0{\cdot}81$ mm, with a range of 5·0–19·1 mm. There was a slight increase in scallop spat size with depth ($r=0{\cdot}113$, $df=530$, $P<0{\cdot}01$), the increment being approximately 1·0 mm over the 12 m range sample.

Of a total of 5 136 animals that settled initially on the spat collectors in the six branch ropes sampled, 2 080 (40·5%) were dead. Taking into account the 10 collection bags that were lost from the 120 bags set out initially, the mean yield of live spat per bag for the six lines examined was 28. If the same rate of loss occurred in the other lines, the total loss was 333 bags and the net yield was about 103 000 seed scallops.

Frequently the polyethylene sheets were folded over to a degree that reduced the surface area available for settlement.

4 Discussion

This study indicates the biological feasibility of collecting giant scallop spat in numbers large enough to allow culture of the species. The observations also indicate that, in Little Bay, Newfoundland, maximum scallop settlement occurred in depths greater than about 4 m; the lower limit to scallop settlement has not been ascertained. Because of predation by starfish (*Asterias vulgaris*), live spat were found mostly in bags held at depths greater than 8 m.

[1] Reference to trade name does not imply endorsement of commercial product by the Department of the Environment, Fisheries and Marine Service, the Marine Sciences Research Laboratory, Memorial University of Newfoundland or FAO.

Variation in settlement of both starfish and scallops between bags held at the same depth may relate to orientation of the bags to the current, the degree of fouling, and the extent to which the polyethylene film becomes folded within the bag. The same factors may influence the variation in spat numbers in bags suspended at different depths. In addition, behaviour of larvae of both scallops and starfish must also influence their initial vertical distribution in numbers. The decrease in the numbers of spat and starfish toward the lower end of the line may be related to factors associated with bottom conditions. Increased turbidity near the bottom with consequent clogging of the meshes in the bag could prevent successful settlement and subsequent survival in these bags.

Vulnerability of small scallops to starfish predation in the upper bags could be reduced. *A. vulgaris* spawns mainly in August and has a larval period lasting for about 3–4 weeks (Evans, Scaplen and Idler, 1973). The protracted major spawning of the giant scallop usually begins somewhat later, reaching a peak in September in Port au Port Bay (Naidu, 1970). The larval period, as determined by the time lag between peak spawning and peak settlement, is about 40–45 days at 10–12°C. Setting of collectors could thus be delayed until about one week after peak scallop spawning. This would give the gear sufficient time to 'condition' in the water and reduce pre-settlement fouling that can exclude successful settling of seed scallops. The need for correct timing of setting out of collectors has been demonstrated in Japan where forecasting techniques based upon gonadal index, cumulative water temperature, and size composition of swimming larvae have been developed (Itò, Kanno and Takashashi, 1975).

Protected collectors, while retaining scallops after byssal detachment, also tend to prevent the escape of young starfish. Predation by starfish is thought to be the most important factor influencing survival of spat in this study, especially in the upper 10 bags. Starfish abundance was probably underestimated since their remains decompose and disappear from the bags. Dead scallops under 1·5 mm could also be lost, but cluckers or disarticulated valves of larger spat would be retained. As the two species appear to have different rates of settlement at different depths, as indicated by the relative abundance of starfish and scallops, it would be advantageous to have the first collecting bag deeper than 8 m.

On the basis of these observations it is suggested that, in Little Bay Mortier, spat collectors be set immediately after peak scallop spawning in depths exceeding 8 m. The lower limit will depend on water depth and siltation rate. In addition, the polyethylene sheets should be secured inside the bags (*eg*, by sewing) to reduce folding within the bags.

5 Acknowledgements

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Pearl Farming in Japan

S. Mizumoto

Abstract

Several species of pearl oyster, *Pinctada fucata, P. maxima, P. margaritifera, Pteria penguin* and *Hyriopsis schlegeli*, are used for pearl farming. The first four species are marine bivalves; the fifth is a freshwater species. Procedures used in *Pinctada fucata* pearl farming consists of preparation of host shell, nucleus insertion, convalescence, nurture and cultivation of mother oysters.

In Japan, the maximum annual pearl production is presumed to be about 35 tons for the *Pinctada* pearl, and 10 tons for the freshwater species.

Major problems facing future pearl farming are security of good culture grounds and preservation of their environmental conditions. Continued studies on the environmental conditions of pearl farming grounds and pearl quality are being conducted in Japan. As a result of these studies and efforts to maintain the culture grounds, good prospects may be expected for pearl farming.

Culture des huîtres perlières au Japon

Résumé

Plusieurs sortes d'huîtres perlières, *Pinctada fucata, P. maxima, P. margaritifera, Pteria penguin* et *Hyriopsis schlegeli* sont utilisées pour la culture des perles. Les quatre premières espèces sont des bivalves marins, la cinquième est une espèce d'eau douce. Les méthodes appliquées pour la culture des perles de *Pinctada fucata* consistent en préparation de la coquille hôte, insertion du noyau, convalescence, soins et culture des huîtres mères. Au Japon, la production annuelle maximum de perles est

évaluée à environ 35 tonnes pour les huîtres *Pinctada* et à 10 tonnes pour les espèces d'eau douce.

Les principaux problèmes que se poseront à la culture des perles sont la sécurité des bons sites de culture et la préservation des conditions du milieu. Des études permanentes sur les conditions de milieu des aires de culture des perles et sur la qualité des perles sont en cours au Japon. Grâce à ces études et aux efforts déployés pour préserver les aires de culture, la culture des perles se présente sous une perspective favorable.

Cultivo de perlas en el Japón

Extracto

Para el cultivo de perlas se utilizan diversas especies de ostras perlíferas: *Pinctada fucata, P. maxima, P. margaritifera, Pteria penguin* y *Hyriopsis schlegeli.* Las cuatro primeras especies son bivalvos marinos, y la quinta una especie de agua dulce. Los procedimientos utilizados para el cultivo de la ostra perlífera *Pinctada fucata* consisten en la preparación de las conchas-soporte, inserción de un núcleo, convalescencia, alimentación y cultivo de ostras reproductoras.

En Japón se supone que la producción máxima anual de perlas es de unas 35 toneladas de perlas de *Pinctada* y 10 toneladas de la especie de agua dulce.

Los principales problemas que se plantearán en el futuro para la cria de ostras perliferas serán conseguir buenas zonas de cria y conservar el medio ambiente. En Japón siguen realizándose estudios sobre las condiciones ambientales de los criaderos de perlas y la calidad de estas últimas. Como consecuencia de estos estudios y de los esfuerzos por mantener las zonas de cria, es de esperar que la cria de ostras perliferas ofrezca buenas perspectivas.

1 Introduction

The techniques of pearl culture are reasonably well known today. For example, almost thirty years ago Cahn (1949) described the basic techniques developed in Japan, and Alargaswami (1970) and others have not only extended this description but have provided additional information on pearl culture in other parts of the world. Nevertheless, for the purposes of a worldwide review of the status of aquaculture it is considered desirable to present a brief account of this example of a highly specialized type of aqua-farming in which the end product is not food but a luxury item whose derivation is dependent upon a complicated set of procedures involving extreme manipulation of the cultured organism.

The pearl culture industry generally uses only five species of bivalve molluscs. Four of these are marine oysters: *Pinctada fucata, P. maxima, P. margaritifera* and *Pteria penguin*; the fifth is a freshwater mussel, *Hyriopsis schlegeli.*

Marine pearls are cultured on the southwest coast of Japan, in the Republic of Korea and in China using *Pinctada fucata* and *Pteria penguin. Pinctada maxima* is used in south Pacific waters (Australia, Burma, Indonesia, and the Philippines). *P. margaritifera* is used in the Okinawa area, Tahiti and Fiji. Freshwater pearls are produced in Japan using *Hyriopsis schlegeli,* and another species of limnetic mussel is used in China.

Additional notes on these species follow:

(*i*) *Pinctada fucata.* This is the species most commonly used for pearl culture in Japan, and the techniques of this culture which produces spherical pearls have been developed primarily with this species. The major producing area for this species in Japan used to be Mie Prefecture, but new farming grounds have been established in the Shikoku and Kyushu areas, because of the deterioration of farming areas and water pollution.

(*ii*) *Pinctada maxima.* About 70–80% of the world's pearl production using this species is cultured in Australia. This species makes the largest round or half pearls having a maximum diameter of 18 mm and a silvery-white colour.

(*iii*) *Pinctada margaritifera.* This species, the 'blacklip pearl oyster' is most suitable for the production of steel-black pearls and half pearls.

(*iv*) *Pteria penguin.* This species, known as 'Mabe' in Japan, is cultured to obtain large-sized half-round pearls. In the Amami-oshima areas of Japan, growers can obtain the spats artificially *in vitro* and use them for culture.

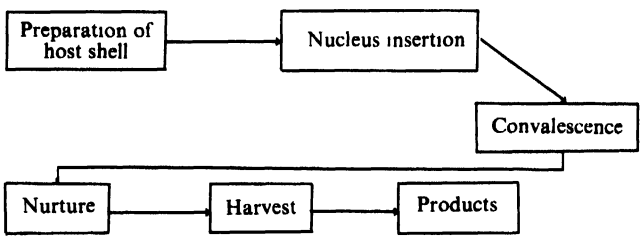
(*v*) *Hyriopsis schlegeli.* Pearl culture with this freshwater mussel has been attempted for 45 years in Lake Biwa near Kyoto and its farming has been extended to several other places during the last decade. For the most part, an artificial nucleus is not employed and the techniques used are different from those used with other pearl-forming molluscs. The colour of the pearl is salmon pink, the shape and size are variable, and they are much appreciated as distinctive pearls.

In China, many freshwater pearls are produced with other species, but the details are not well known to the author.

Table I shows the amount of pearls produced in Japan.

2 Farming procedure

As *Pinctada fucata* is the main species used in pearl production, and as the major techniques have been developed with this species, it will be used as an example to describe pearl farming procedures. Each step in pearl culture is dependent upon a knowledge of the biology and life history of the pearl oyster, and careful adherence to each step in the procedure is very important for producing pearls of good quality. The steps are as follows:



2.1 *Preparation of host shell*

The best site in the body of this pearl oyster for insertion of a nucleus for pearl formation is the gonad. When a gonad contains eggs or sperm, it is difficult to obtain good results in this operation and one can not expect to grow pearls of good quality. The period that the gonad is devoid of gametes comes just after spawning and has short duration. There is, therefore, a necessity to extend this limited period for the nucleus-insertion operation artificially. Two methods are used to improve gonadal conditions for the operation; suitable conditions for the operation can be expected using either treatment:

(*i*) *Inhibition of maturation.* This treatment is usually applied to oysters for the operation in April-May. During the previous season, after spawning, oysters with no eggs or small eggs are selected and placed under low temperatures to inhibit gonad maturation.

(*ii*) *Acceleration of maturation.* Under this treatment, early maturation of the gonad is expected and the oysters are spawned before the operation. Normally, the oysters are put in a cage where they are a little crowded and placed in warm temperatures in the sea. If conditions are suitable, early maturation can be expected. After they mature, the oysters are stimulated to induce spawning. Usually,

TABLE I
NUMBER OF MANAGEMENT UNITS AND QUANTITIES OF CULTURED PEARLS PRODUCED IN JAPAN (1926–73)

Year	Pearl cultured with *Pinctada fucata*[1]		Pearl cultured with *Hyriopsis schlegeli*[1]		Pearl cultured with *Pinctada maxima*[2]		
	Number of management units	*Quantities of cultured pearls produced (kg)*	*Number of management units*	*Quantities of cultured pearls produced (kg)*	*Number of management units*	*Quantities of cultured round pearls produced (kg)*	*Number of cultured half pearls produced*
1926	33	251					
1927	42	220					
1928	47	668					
1929	50	241					
1930	62	307					
1931	51	405					
1932	108	1 370					
1933	147	935					
1934	320	1 691					
1935	222	2 906					
1936	258	2 651					
1937	274	4 071					
1938	289	4 081					
1939	281	3 930					
1940	—	3 470					
1941	336	2 959					
1942	107	2 261					
1943	107	1 580					
1944	107	731					
1945	107	275					
1946	—	188					
1947	—	450					
1948	187	934					
1949	314	1 875					
1950	359	3 750					
1951	700	7 500					
1952	1 200	10 500					
1953	1 200	13 328					
1954	1 456	16 890					
1955	1 643	24 525	6	112			
1956	1 734	26 444	6	176			
1957	2 574	29 701	9	356			
1958	3 001	47 662	23	423	2	18	26 184
1959	3 084	50 119	37	1 189	2	25	30 263
1960	3 484	59 486	37	922	2	39	27 862
1961	3 637	71 894	37	1 082	2	58	37 893
1962	3 817	78 032	40	1 019	3	97	128 992
1963	4 079	86 407	41	1 972	5	76	150 230
1964	4 302	87 021	46	1 564	6	119	181 439
1965	4 620	111 460	46	2 602	8	139	185 323
1966	4 710	127 460	48	2 836	6	173	209 103
1967	4 666	122 451	48	3 961	7	130	205 996
1968	4 606	99 717	53	4 669	7	174	346 338
1969	4 226	95 745	57	5 902	6	229	390 520
1970	3 635	74 678	58	6 884	8	272	177 472
1971	2 962	48 601	61	7 173	6	308	118 338
1972	2 823	42 296	61	7 218	5	437	118 003
1973	2 526	34 436	62	6 848			

[1] Statistics compiled by the Japanese Ministry of Agriculture and Forestry and by the Fisheries Agency
[2] Statistics compiled by the Japan Export Overseas Pearl Producer's Association

changing the hanging layer of their cages is sufficient stimulation. After spawning, the oysters are placed under conditions which promote recuperation from the treatment. When they resume a normal condition, they are ready for the nucleus-insertion operation.

2.2 *Preparation for nucleus-insertion*

2.2.1 *Opening of host shell.* Before the operation, many host oysters must be prepared. The oysters are placed in a shallow tray with the hinge or dorsal portion of the shell downward and covered with sea water. Within a few minutes, the valves start to open. Shell openers are gently inserted between the valves to open them wider and a bamboo wedge or key is then applied to keep them open.

Other methods may be employed to open the shells but the mortality rate for oysters prepared by this procedure is lower than when others are used.

2.2.2 *Preparation of graft tissue.* Proper preparation and careful insertion of the graft tissue governs, to a large extent, the production of the pearl. The graft tissue is obtained from the pallial zone of living oyster mantle. The oyster is opened carefully with a sharp knife and the adductor muscles are cut from their point of attachment to the shell. The major care in this operation is to remove the mantle without injury. All extraneous matter is scraped out using the blunt edge of a scalpel.

A strip about 2–3 mm wide is then cut from the pallial zone of the mantle. Every operation must be performed carefully and gently because rough treatment can damage the epithelium in the pallial zone of the mantle. The strip is cut into pieces 2–3 mm square. The size of these squares is determined by the size of the nucleus to be used, each graft being sufficiently large to cover one third of the nucleus.

Under moderate temperature, 17°–22°C, the graft tissue will live for about two hours if kept moist with sea water.

2.2.3 *Preparation of the nucleus.* Layers of nacre bind most satisfactorily with calcareous substances; for the final product the nuclear material should have the same or similar characteristics of deposited nacre. The shells of other molluscan species are therefore used for the nucleus.

In preparing nuclei the donor shells are cut into small cubes of the general size required and then placed between two sheets of iron. As the upper sheet is revolved, the cubes are ground between the plates and against one another to produce rough spheres. Further finishing work is done to make them smooth but a high polish is not essential. Although the general size of the finished product is determined by the size of the original cube, some variation occurs, and finished nuclei are graded according to their diameter.

2.2.4 *Surgery on the oyster.* The organ in which the nucleus or nuclei will be inserted is the gonad. As other organs, such as the adductor muscle, hepatopancreas, intestine and byssus gland are located around the gonad, the surgery must be performed without injury to them. The number of nuclei to be inserted depends upon the size of the nuclei. Two to five nuclei are put into an oyster if they are 3 mm or less in diameter; one nucleus is inserted when it is larger than 3 mm.

The operation is usually carried out during the period from spring through autumn but it should not be done during the hot summer or rainy season.

2.2.5 *Insertion of nucleus.* When the partly open pegged oyster has been placed in an oyster clamp and the graft tissues have been prepared, the operator smooths back the mantle folds with a spatula exposing the foot and main body. An incision is made in the gonad, the graft mantle tissue is then inserted and nucleus-insertion follows. The graft tissue must be placed on the nucleus.

A highly skilled technican can insert from two to five nuclei in an oyster, usually completing these operations on 25–40 oysters per hour.

2.3 *Convalescence*

The operated oysters are placed in culture cages, consisting of heavy wire frames (68 × 60 × 30 cm) covered with fine mesh wire netting, each of which can hold 50–60 oysters. The cages, suspended horizontally from rafts, should be placed in an area with calm conditions to avoid disturbance for four to six weeks after the insertion operation.

During this period of convalescence, the oysters recover from the operational shock and repair whatever injuries have been sustained. At the end of this period, the cages are lifted and the oysters are inspected. All dead shells are removed and the cages are transferred to ordinary culture rafts.

2.4 *Pearl formation on the nucleus*

In oysters where the operation has been successful, the graft tissues begin to grow; they form 'pearl-sacs' which completely cover the nuclei. After the sacs are formed, the epithelial cells secrete a nacreous or pearly substance and deposit it on the surface of the nuclei. It usually takes three to four years for pearls of commercial value to develop.

2.5 *Subsequent culture*

The cages are suspended from rafts or long lines at a depth of 2–3 m. At least three times a year, the cages are lifted, all encrusting marine organisms are removed from the oysters, and the cleaned oysters replaced under the raft. A few oysters are picked out to determine the rate of pearl growth. Normal harvesting operations begin in October and continue until the middle of January.

2.6 *Nurturing procedure*

2.6.1 *Facilities.* At one time the sowing method was applied in nurturing pearl oysters but, at present, all pearl farming uses a hanging method with rafts or long lines.

(*i*) The use of rafts: Two kinds of materials are generally used for raft construction: logs or bamboo. (Steel pipe has been used recently but its use is not yet common.)

Log rafts. Cypress or cedar logs are used for these rafts. The standard size of a log raft is about 6·4 × 5·5 m and four floats are attached underneath the raft. A hundred ropes are usually hung from a raft and each rope holds a cage. A standard-sized cage, about 70 × 45 cm, composed of synthetic fibre net, contains about 60 oysters.

Bamboo rafts. Two poles of bamboo trunk, 9–10 m long, are tied together, and put on the surface of the water parallel to each other at intervals of about 2 m. Usually 15–20 ropes with cages are hung on a raft of 15 m length. The raft can float on the surface without floats.

(*ii*) The use of long lines: A rope is attached to a spherical plastic float. This system, which is stronger than rafts in rough weather, is placed outside a bay or inlet. The cages that hang under the rope are similar to those used with rafts.

2.6.2 *Hibernation.* The pearl oyster was originally a semi-tropical or temperate organism. Optimal temperature for its growth is 20°–25°C; the minimum is 8°C. In winter time, therefore, it is common practice among growers to let these oysters hibernate—placing them in warm water to keep physiological conditions normal.

2.6.3 *Other specialized treatment.* The growth rate of pearl or nacre on the nucleus and the quality of pearl produced depend upon water conditions and usually waters which provide a good growth of pearl do not always produce good quality pearls. Conversely, waters which produce pearls of good quality are not suitable for good growth. Therefore, growers move their oysters to different places to obtain better products. When farming begins, the growers first put their oysters in places where they will get good growth; later they transport them to areas where a better quality of pearl is expected.

These differences are due to water quality, especially to its fertility, and sometimes the oysters are moved a few hundred kilometres to achieve these ends.

3 Enemies and damages

There are many constraints on pearl farming. Among natural factors, damage from parasites is the most serious problem. Among the parasites are polychaete worms which are harmful to pearl formation and the physiological functions of oysters. Oysters invaded by polychaetes are first soaked in fresh water to make the shells close tightly so that the oyster itself may avoid the effects of salt water. They are

then soaked in highly concentrated salt water for 20–25 minutes to eliminate the polychaete.

Trematodes also sometimes cause serious damage to the oysters. The only practical control of these parasites is to transfer the pearl oysters from infected to non-infected waters in September; the month when trematode invasion normally takes place. (It is impossible to remove the host fish from coastal areas.)

Unsuitable physical and chemical environmental conditions are also serious hazards for pearl oyster farming. Among these factors are: decrease in salinity, high water temperatures, cold tides, red tides, hydrogen sulphide and pollution by domestic and industrial effluents. Areas where these unsuitable conditions can be frequently observed should be avoided by pearl farmers.

4 The supply of mother oysters

Although native oysters were previously used, today's supply comes mainly from oyster farms because of the decrease in natural stock.

The free-swimming veliger larvae of the pearl oyster have a markedly negative phototropic behaviour just before setting and this reaction is utilized for the collection of spat artificially. Cedar tree leaves and palm tree bark are usually used as collectors. These materials are combined and put into the water during the spawning season, July-September. During this period, the spat attach on the collectors, and remain in place until late November when they become young oysters, about 1·5 cm long. They are then removed from collectors and transferred into rearing cages for growth. The cages are hung under rafts or long lines. It usually takes about two years for the host shell to develop to the stage required for pearl farming.

5 Future of pearl farming

Beautiful pearls are desired by many people. One cause of a slump in pearl farming in Japan was caused by an unsuitable price due to the increase in pearls of poor quality. Mere increased production of pearls in the future is not visualized; the aim of the industry should be to improve the quality of cultured pearls. If this planned production of pearls is carried out, pearl farming may have a bright future.

The maximum pearl production in the future is expected to be about 35 tons/year of *Pinctada* pearl, and that of the freshwater one about 10 tons in Japan. As a pearl market for *Pinctada maxima, P. margaritifera* and *Pteria penguin* pearls opens, production of pearls may be governed, to some extent, by supply and demand. If a method which includes artificial seed production technique is established more stable production of pearls may be expected in *Pinctada maxima* and *P. margaritifera.*

There may be considerable difficulties to apply the techniques established for *Pinctada fucata* to the culture of other pearl oysters. Physiological and ecological studies on each species will be required concerning pearl formation. Through these studies, new techniques which will be suitable for each species can be established.

For the further prosperity of pearl farming, not only must culture techniques be improved but, simultaneously, studies should be made in various areas and under different environmental conditions to resolve problems with respect to pearl qualities, *eg,* lustre and formation of the pearl layer. Finally, steps must be taken to secure good culture grounds and a continued vigilance exercised to preserve them from environmental deterioration.

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Shellfish Purification: A Review of Current Technology

S. A. Furfari

Abstract

The controlled purification of molluscan shellfish by natural biological processes is widely known and has been researched since the turn of the century. The process is an integral and mandatory part of the shellfish industry in England, France and Spain. It is little known or practised in the USA and although sporadically used in Portugal, Japan and Canada, has never been an integral or major part of the shellfish industry there.

The need for purification arises from a need to protect public health from shellfish which are notorious for concentrating pathogenic micro-organisms from sewage-polluted sea water. Assessment of pollution in harvest areas is difficult and never certain. Purification may also be used to reduce the unknown hazard of viral pathogens, especially infectious hepatitis which is difficult to monitor either in the environment or in shellfish.

A synopsis of commercial purification plants shows that they have been operated for soft clam (*Mya arenaria*), hard clam (*Mercenaria mercenaria*), Pacific oyster (*Crassostrea gigas*), European oyster (*Ostrea edulis*), Portuguese oyster (*Crassostrea angulata*), mussel (*Mytilus edulis*), chirla (*Venus gallina*) and other species.

Development of purification plants in the USA has lagged and only the soft clam is currently being purified on a commercial scale. Possibly the industry is reluctant to invest in new purification plants because of belief that the massive sewage treatment plant construction programme now in progress in the USA will eliminate much of the hazard of polluted harvest beds. There is also some distrust of the value of viral depuration, especially of hepatitis. Nevertheless, operation of various plants (commercial and pilot) in both the USA and Canada has demonstrated the economic, technical and biological feasibility of the process in North America.

Despite all that is known about molluscan shellfish biology, no reliable biological or physiological phenomena quantitatively demonstrate successful purification of pathogenic micro-organisms. The only way to assure that purification has taken place is by the use of bacterial indicator systems.

Generally speaking, viral accumulation and depletion rates follow that of coliform for the species studied. The fact that virus can be removed is not at issue any longer. It is the initial level of virus in the mollusc that is the crux of the matter.

The engineering design and operation of a purification plant are predicated on maintaining the proper biological state of the molluscs, especially with respect to their excretory, nervous, respiratory, musculoskeletal and reproductive systems.

Fundamentals of plant design include: (*i*) plant siting (water supply—amount, type, method of delivery, *etc*); (*ii*) plant structure (materials, whether indoor or outdoor); (*iii*) plant layout (consideration of efficiency and product flow, and positive separation of purified from unpurified shellfish); (*iv*) handling (whether by carts, trolleys or belts, in baskets or in bags); (*v*) sea water systems (plastic pipe and advance engineering are recommended); (*vi*) water supply and treatment which will ensure that shellfish receive processed water comparable with their biological systems and not become contaminated in that water (temperatures of 10–20°C, oxygen content of 5 mg/l to saturation, turbidities of

20 JTU, and salinities with 20 ‰ of the value at harvest areas are generally advised); (*vii*) water treatment for microbials (whether chlorination or, as have generally supplanted it, ozone or ultra-violet (UV) light); (*viii*) purification tank design which will ensure uniform hydraulic flow, proper stocking of containers, cleanability, prevention of disturbance and contamination of shellstock.

Research needs include: (*i*) continuation of virus model studies to determine how viruses enter and leave the shellfish; (*ii*) a complete interdisciplinary study of process needs to relate studies by bacteriologists and virologists to basic biology, engineering or chemistry, and (*iii*) effects of recirculating systems on artificial sea water, the deterioration rate of sea water and removal of metabolic waste products.

Purification des mollusques: Examen de la technologie actuelle

Résumé

La purification sous contrôle des mollusques par des processus biologiques naturels est bien connue, et a fait l'objet de recherches depuis le début du siècle. En Angleterre, en France et en Espagne, il s'agit là d'un élément intégré et obligatoire de l'industrie des mollusques. Cette purification est peu connue ou n'est guère pratiquée aux Etats-Unis, et bien qu'elle soit pratiquée de temps à autre au Portugal, au Japon et au Canada, elle n'a jamais été partie intégrante de l'industrie des mollusques dans ces pays.

La purification résulte de la nécessité de protéger la santé publique vis-à-vis des mollusques dont on sait qu'ils concentrent les micro-organismes pathogènes provenant de l'eau de mer polluée par les effluents. L'évaluation de la pollution dans les aires de récolte est difficile et manque de précision. La purification peut également servir à réduire les dangers imputables aux virus pathogènes, notamment celui de l'hépatite infectieuse qu'il est difficile de surveiller tant dans l'environnement que dans le mollusque.

Un tableau récapitulatif des usines de purification commerciale montre qu'il en existe pour la mye (*Mya arenaria*), le clam (*Mercenaria mercenaria*), l'huître du Pacifique (*Crassostrea gigas*), l'huître d'Europe (*Ostrea edulis*), l'huître portugaise (*Crassostrea angulata*), la moule (*Mytilus edulis*), le petit clam (*Venus gallina*), et d'autres espèces.

La construction d'usines de purification aux Etats-Unis a pris du retard et seule la mye est couramment purifiée à une échelle commerciale. Il se peut que l'industrie répugne à investir dans de nouvelles usines de purification parce que l'on espère que le vaste progamme de construction d'installations de traitement des eaux usées actuellement en cours d'exécution dans le pays éliminera une bonne partie des risques imputables à la pollution des gisements de mollusques. Il existe également une certaine méfiance à l'égard de la dépuration virale, notamment en ce qui concerne l'hépatite. Néanmoins, le fonctionnement d'un certain nombre d'usines (tant commerciales que pilotes) à la fois aux Etats-Unis et au Canada a démontré la possibilité en termes économiques, techniques et biologiques, de mettre en œuvre ce processus en Amérique du Nord.

Malgré toutes les connaissances dont on dispose sur la biologie des mollusques, aucun phénomène biologique ou physiologique fiable n'a pu fournir une démonstration quantitative de la purification des micro-organismes pathogènes. La seule manière de s'assurer que cette purification est effective est de recourir à des indicateurs bactériens.

D'une manière générale, les taux d'accumulation et de résorption virales correspondent à ceux des coliformes pour les espèces étudiées. La possibilité d'éliminer le virus n'est plus en doute. C'est le taux initial d'accumulation virale dans le mollusque qui est au cœur du problème.

La conception technique et le fonctionnement d'une usine de purification visent au maintien adéquat de l'état biologique des mollusques, notamment du point de vue de leurs appareil excréteur, nerveux, respiratoire, musculo-squelettique et reproductif.

Les éléments de base de l'installation sont les suivants: (*i*) site de l'usine (approvisionnement en eau—quantité, type d'amenée, *etc*); (*ii*) structure de l'usine (matériaux, installation en système clos ou à ciel ouvert); (*iii*) disposition des lieux (examen de l'efficacité et de l'écoulement des produits, séparation effective entre mollusques purifiés et mollusques non purifiés); (*iv*) manutention (par charrettes, trolleys ou courroies transporteuses, en paniers ou en sacs); (*v*) systèmes d'eau marine (les tuyauteries en plastique et les techniques de pointe sont recommandées); (*vi*) approvisionnement en eau et épuration assurant aux mollusques une eau traitée comparable à celle de leur système biologique et non susceptible de les contaminer (l'on recommande généralement des températures de 10 à 20°C, une teneur en oxygène de 5 mg/l à saturation, des turbidités de 20 UTJ et des salinités de 20 ‰ de la valeur dans les zones de récolte); (*vii*) traitement de l'eau pour les micro-organismes (soit par chloration, soit par l'ozone ou les ultra-violets, méthodes qui se sont généralement substituées à la précédente); (*viii*) plans des réservoirs de purification assurant un flux hydraulique uniforme, le stockage adéquat des conteneurs, la possibilité du nettoyage, la prévention des troubles affectant le stock de mollusques et de sa contamination éventuelle.

La recherche doit porter notamment sur les points ci-après: (*i*) continuation des études de modèles visant à déterminer comment les virus pénètrent dans le mollusque et en sortent; (*ii*) une étude interdisciplinaire complète des besoins de traitement visant à établir un lien entre les études des bactériologistes et des virologistes et la biologie, la technique ou la chimie fondamentales, et (*iii*) effets des systèmes de recyclage sur l'eau de mer artificielle, taux de détérioration de l'eau de mer et évacuation des déchets du métabolisme.

Depuración de moluscos: Examen de la tecnología actualmente utilizada

Extracto

La depuración controlada de moluscos mediante procesos biológicos naturales es bien conocida y ha sido objeto de investigaciones desde principios del siglo. El proceso de depuración constituye parte integral y obligatoria de la producción de moluscos en Inglaterra, Francia y España. En los Estados Unidos es poco conocida o aplicada y aunque en Portugal, Japón y Canadá se ha utilizado esporádicamente, nunca ha sido parte integral o importante de la industria de producción de moluscos.

La necesidad de depuración deriva de la necesidad de proteger la salud pública contra la capacidad que tienen los moluscos de concentrar los micro-organismos patógenos presentes en las aguas de mar contaminadas por descargas de alcantarillado. La evaluación de la contaminación en las zonas donde se explotan los moluscos es difícil y nunca totalmente segura. La depuración puede utilizarse también para reducir los riesgos desconocidos de patógenos virales, especialmente hepatitis infecciosa, cuya presencia en el medio ambiente y en los moluscos es difícil de determinar.

Una sinopsis de las plantas comerciales de depuración muestra que se han utilizado para la almeja blanda (*Mya arenaria*) y la almeja dura (*Mercenaria mercenaria*), ostra del Pacífico (*Crassostrea gigas*), ostra europea (*Ostrea edulis*), ostra portuguesa (*Crassostrea angulata*), mejillón (*Mytilus edulis*), chirla (*Venus gallina*) y otras especies.

La construcción de plantas depuradoras en los Estados Unidos ha procedido con lentitud y en la actualidad sólo se depura a escala comercial la almeja blanda. Tal vez la industria sea reacia a invertir en nuevas plantas depuradoras por creer que el programa masivo de construcción de plantas para el tratamiento de aguas residuales actualmente en curso en los Estados Unidos eliminará buena parte de los peligros derivados de la contaminación de los parques de cultivo. Hay además cierta desconfianza sobre el valor de la depuración de virus, especialmente por lo que se refiere a la hepatitis. De todas formas, el funcionamiento de varias plantas (comerciales y piloto) en los Estados Unidos y Canadá ha demostrado la viabilidad económica, técnica y biológica de este proceso en América del Norte.

A pesar de cuanto se sabe sobre la biología de los moluscos, no hay ningún fenómeno biológico o fisiológico fidedigno que revele cuantitativamente que la depuración de micro-organismos patógenos ha tenido éxito. La única forma de asegurarse de que la depuración ha tenido lugar es utilizando indicadores bacterianos.

En general, la tasa de acumulación y eliminación de virus, en la especie de que se trate, responde a la de coliformes. Del hecho de que puedan eliminarse los virus ya no se duda. El enigma es cuál es el nivel inicial de virus en el molusco.

En el diseño de ingeniería y funcionamiento de una planta de depuración se tiene en cuenta el mantenimiento del buen estado biológico de los moluscos, especialmente en lo que se refiere a sus sistemas excretorio, nervioso, respiratorio, músculo-esquelético y reproductivo.

Entre los aspectos fundamentales que hay que tener presentes en el diseño de las plantas figuran: (*i*) emplazamiento (suministro de agua: cantidad, tipo, método de abastecimiento, *etc*); (*ii*) estructura (materiales, ya sea bajo techo o al aire libre); (*iii*) disposición de la planta (eficiencia y entrada y salida del producto; clara separación de los moluscos ya depurados de los no depurados); (*iv*) manipulación (en carretillas o cintas transportadoras, en cestas o bolsas); (*v*) sistemas de agua de mar (se recomiendan tuberías de plástico y técnicas avanzadas); (*vi*) abastecimiento y tratamiento de aguas, para asegurar que los moluscos reciban agua que corresponda a sus sistemas biológicos y no se contaminen en esas aguas (se aconseja, en general, temperaturas de 10–20°C, contenido de oxígeno de 5 mg/l a saturación, turbidez de 20 unidades de Jackson (UTJ), salinidad que se mantenga dentro del 20 ‰ de la de la zona de explotación); (*vii*) tratamiento del agua para eliminación de microbios (con cloro, ozono o rayos ultravioleta (UV)); (*viii*) diseño del tanque de purificación que asegure un flujo uniforme del agua, una colocación adecuada de los contenedores, la posibilidad de limpieza y la prevención de perturbaciones y contaminación de los moluscos.

Entre las investigaciones necesarias figuran: (*i*) proseguir los estudios modelo sobre virus, para determinar cómo entran y salen de los moluscos; (*ii*) realizar un estudio interdisciplinal completo del proceso, para poner en relación los estudios realizados por bacteriólogos y virólogos con las consideraciones biológicas, ingeniería o químicas básicas, y (*iii*) estudiar los efectos de los sistemas de circulación en el agua artificial de mar, índice de deterioramiento del agua del mar y la eliminación de desechos metabólicos.

1 Introduction

Controlled purification of molluscan shellfish has been a recognized process throughout the world for many years. The research literature on the efficacy of this natural

biological process begins at about the turn of the century (Dodgson, 1928). Basic and applied research has been done in the United Kingdom, Spain, France, Italy, Sweden, Portugal, Japan, Canada and the United States (Furfari, 1966).

In England, France and Spain the process is an integral and mandatory part of the shellfish industry and has been routinely used for many years. By contrast, in the United States, purification of shellfish is little known to the general public, and except for a few localities, the shellfish industry is not cognizant of the value of the process. The process has been sporadically used in Portugal, Japan, and Canada, but it has never been an integral or major part of the shellfish industry there.

The purposes of this paper are to: describe the depuration process, discuss current commercial practices and public health ramifications of depuration, and review engineering parameters of the process.

2 Public health justification

In discussing the justification for the process, complexities arise because of the various philosophies of the countries using the process. For example, in the United States, harvesting areas are deemed polluted by virtue of low water quality, and are closed to shellfishing for direct market harvesting if the median total coliform concentration generally exceeds 70/100 ml. In most other countries, however, harvest areas are classified according to the bacteriological quality of shellfish meats. In Europe, shellfish may be harvested for purification regardless of water quality. This is not the case in the United States where levels of bacteria in water and shellfish prevent harvesting despite the possible use of a purification plant.

The need for purification arises from a need to protect public health, which is based on a continued desire on the part of the public to eat raw or inadequately cooked molluscan shellfish—shellfish are notorious for concentrating pathogenic micro-organisms from sewage-polluted sea water.

Each year, populations increase along the coasts with resulting increases in sewage pollution reaching the waterways. Efforts are underway in many countries to treat and disinfect sewage, but the population growth rate may be exceeding attempts to do so. Furthermore, the adequacy of sewage treatment is often questionable because of equipment and operational failures, frequent overflows as a result of rainfall, and by-passing of raw sewage. There are several reasons for by-passing: maintenance of equipment, flooding because of high stages of receiving waters, and slugs of untreatable industrial wastes, to list a few.

Shellfish control authorities cannot be assured that all harvesting areas within the influence of municipal sewage will never become polluted. There always remains an element of risk. To assess the probability of contamination is difficult. Establishing a surveillance programme over such harvest areas is difficult because a sampling programme is costly and time-consuming. Thus, purification of shellfish in plants is an alternative to no harvesting and it is thought of in the context of an added safety factor.

Another reason for using purification is to reduce the unknown hazard of viral pathogens, especially infectious hepatitis. Viral pathogens are extremely difficult and costly to monitor, in both the environment and shellfish. Laboratory methodology for detection of infectious hepatitis is non-existent. There are no standards for viruses in shellfish, yet there are many reports of infectious hepatitis transmission by the American oyster (*Crassostrea virginica*) and hard clam (*Mercenaria mercenaria*) (Liu, Seraichekas and Murphy, 1967). More recently, concern was raised about approved area oysters, *Crassostrea virginica*, which transmitted hepatitis to more than 200 people in two cities in the United States (Portnoy, 1975). The cities are 800 miles (1 287·5 km) apart and the oysters were harvested from an area remote from them. Because of the repeated outbreaks of hepatitis which have been documented over the past 20 years, the need to purify all molluscan shellfish which are or may be subjected to direct or indirect sewage pollution will confront health officials more and more.

3 Synopsis of commercial plants

Table I gives some basic information on existing or recently operated purification plants. These plants provide a wide variety of water treatments, tank designs, hydraulics, and operations. (The list is not comprehensive for European countries as the necessary information is not currently available to the author.)

The plant in British Columbia, Canada, is not active nor is the larger plant in Maine which operated for about five years. Recent, but short-lived, pilot-commercial plants have been built and tried in Rhode Island (1964), Florida (1966), New York (1968), Delaware (1970), and California (1974). These ventures were not fruitful for a variety of reasons including poor business practices, lack of proof of efficacy, and/or inadequate planning.

3.1 *Development in the USA*

Commercial plants for American oysters, hard clams, and soft clams (*Mya arenaria*) have been sporadically tried in the United States but only the soft clam is currently being purified on a commercial scale on the northeastern seaboard. Why this situation exists is not really known since many oyster beds and hard clam areas throughout the United States are not being harvested because of moderate pollution. One explanation is that, because of the massive sewage treatment plant construction programme in the USA, the shellfish industry is somewhat reluctant to invest in new shellfish purification plants which may not be needed in just a few years.

However, another reason relates to the fact that soft clams usually are fried or steamed but oysters and hard clams are eaten raw in large amounts. Thus, there is some distrust of the process, a paradox in view of the years of the European experiences. The distrust in the process relates mainly to viral depuration, especially of hepatitis. There are a considerable number of works on viral depuration (section 4.3) but none on hepatitis. The United States has spent several million dollars researching viral depuration and the limitations have been shown. Debate on this aspect still exists.

The soft clam plant in Massachusetts, which was built about 1930, is still operating. The basic tanks and layout have been used throughout the period of operation. Modifications in its operations have changed to keep up with the latest research on biology and engineering. Originally, water was treated with chlorine and recirculated using an aeration/lift principle. The water is still being recirculated but by means of pumps and is still aerated to maintain

TABLE I
SYNOPSIS OF PURIFICATION PLANTS

Country	*State, province, etc.*	*Species*	*Capacity (approximate) for shellstock (m^3)*	*Water treatment*[1]	
USA	Maine	Soft clam (*Mya arenaria*)	4·3	UV	Plant closed in 1975 for refurbishing flow-through seawater system
	Maine	Soft clam (*M. arenaria*)	1·5	UV	Three such small plants are active in the city of Scarboro. Some use saltwater wells
	Massachusetts	Soft clam (*M. arenaria*)	12·1	UV	This plant was built about 1930 and converted from chlorination about 1960. Uses recirculation
	New Jersey	Soft clam (*M. arenaria*)	10·0	UV, FILT	This plant was a converted lobster pool. Uses recirculating system
	New York	Hard clam (*Mercenaria mercenaria*)	2·0	UV, FILT, SED	Operated 1968–69 for pilot and feasibility studies
Canada	British Columbia	Pacific oyster (*Crassostrea gigas*)	3·6	UV	This plant operated from 1969 to 1972 for experimental and commercial purposes
UK	England	European oyster (*Ostrea edulis*)	Varies	UV	Approximately 20 commercial plants; mostly small local operations
	Wales	Mussel (*Mytilus edulis*)	—	CL	Plant constructed in 1928. Uses a static or batch seawater system
Spain[2]	Gerona	Mussel (*M. edulis*) Portuguese oyster (*Crassostrea angulata*) European oyster (*Ostrea edulis*) Chirla (*Venus gallina*) Clams	[3]	OZ	Several tanks with area of 1 020 m^2
	Tortosa	—	—	OZ, FILT	22 tanks each 30 m^2
	Cadiza	—	—	Solar	Recirculation system
	Huelva	—	—	Solar	Recirculation system
France[4]	Sète	Mussel (*Mytilus edulis*) Portuguese oyster (*Crassostrea angulata*) European oyster (*Ostrea edulis*)	—	OZ	
	Plougasnou	—	—	OZ	
	Le Crotoy	—	—	OZ, FILT, SED	

[1] UV—ultraviolet light; CL—chlorination; OZ—ozonation; FILT—filtration; SED—sedimentation
[2] See San Feliu (1973)
[3] In 1960, 1 100 tons of shellfish; in 1970, 1 735 tons
[4] Personal communication J. LePauloue, Trailigaz, Paris (1975)

oxygen levels. The water treatment, however, is being done now by ultraviolet (UV) light. The construction of the UV units follows the design of Kelly (1961). Monitoring of the process is no longer by the fermentation tube test for coliform, but by the elevated temperature plate test (Cabelli and Heffernan, 1970). Section 5 on monitoring and controls discusses this further.

Despite the long tradition of soft clam depuration in Massachusetts, workers in Maine wished to improve the process. Goggins *et al* (1964) demonstrated a flow-through system for smaller tanks and provided more detailed studies on the biological aspects of soft clam purification. The results of the pilot-scale research provided a basis for establishing methods of standardizing the purification process for other species.

Commercial soft clam plants of various sizes were subsequently constructed in Maine, but only three small plants are operating today. The Maine experiences showed that the use of salt water wells was not detrimental to the process, that flow-through systems were economically feasible and that small wooden tanks and plastic-coated wire baskets were quite desirable, and thus, the process economically feasible. The soft clam washer was another significant development. It provided for minimal breakage, excellent cleaning of mud, and culling.

The large soft clam plant in New Jersey offers a unique situation. The plant is a converted lobster pool. However, the plant contained many features needed for a soft clam purification plant. A year-round source of sea water was available and large underground concrete seawater storage tanks were appropriate for a recirculating process. The numerous (54) wooden tanks and their tiered arrangement offered flexible operation. Furthermore, a seawater cooling system used to maintain the lobsters has proven exceedingly useful for maintaining shelf-life of the soft clams after purification. The drawbacks to this functional conversion are: (*i*) poor product flow; (*ii*) poor tank hydraulics; (*iii*) lack of ability to maintain good separation of treated and untreated clams; (*iv*) small storage space; and (*v*) inability to install the commercially-bought UV units in a safe place. The drawbacks have been tolerated and have caused only minimal operational problems. However, the UV units which are in a corrosive and humid atmosphere have revealed electrical and safety problems. The plant also filters the raw water through fibreglass of the type used for insulation. Another innovation is the use of plastic mesh bags (in lieu of wire baskets). The bags, although less durable than plastic-coated wire baskets, are substantially cheaper (a few cents versus US$ 20). Although the soft clam shells are quite fragile, breakage is minimal because of careful handling.

3.2 *Recent pilot work—USA and Canada*

Two important commercial-pilot plants were operated in

North America in recent years. One was the work on hard clams in New York (1968–69) and the other was the work on the Pacific oyster (*Crassostrea gigas*) in British Columbia (1969–72).

The New York study took a broad approach by testing and considering such aspects as saltwater wells, filtration, settling, aeration, commercial UV units, heat exchange, costs, bacteriological efficacy, and viral depuration. The overall conclusion of the study was that the purification of hard clams was feasible both economically and bacteriologically. This study also considered practical aspects of tank construction, piping, and saltwater well operations and testing. Turbidity problems associated with surface water were handled initially with sand filtration and settling. However, saltwater well testing showed that water of uniform temperature and salinity was available throughout the year. The study recommended the use of a flow-through system using saltwater wells (New York, 1969).

Devlin (1973) provided a summary of the Canadian experiences in purifying *C. gigas* from 1969 to 1972. The economic and biological feasibilities of the process were demonstrated. Careful monitoring of the waters (flow rate, temperature, turbidity, dissolved oxygen) and bacteriological testing of shellfish resulted in cogent operating criteria. UV light was used to maintain levels of bacteria in the sea water and it was shown that the membrane filter was appropriate to monitor the effectiveness of the treatment. Operational problems and expenses were carefully documented to provide the shellfish industry with a good source book of information for that part of the country.

3.3 *European practices*

There is no doubt that Europe is a prime source of information on practical aspects of purification. Several species of molluscs (many eaten raw) are purified and the sea water is being treated with UV, ozone and chlorination (Table I). The European plants have done considerable research with subsequent modifications to improve the process.

Wood (1961) has presented a standardized approach to purification of oysters for the United Kingdom and the many plants follow the methods outlined. He presented criteria for various sizes of plants to accomplish successful purification. The report demonstrates bacterial reduction rates under varying environmental parameters (temperature, salinity, dissolved oxygen, *etc*). It is interesting to note that the UK still uses UV light for water treatment despite the fact that nearly all plants in Spain and France use ozone.

Details of some of the features of European plants are given in a later section.

4 Biological considerations

4.1 *Overall view*

Shellfish must purify themselves; man merely provides the environment conducive to this process. Years of experience and research on biology of molluscan shellfish have provided a large body of knowledge which assists in optimizing this process. The more important environmental factors have been quantified for most commercial species of molluscs.

It is not possible in a report of this size to describe in depth all of the biological considerations but it is appropriate to point out the major aspects. The reasons are that the engineering design and operations of a plant are predicated on maintaining the proper biological state of the molluscs. Table II presents the major physiological systems, the concomitant effects, and the environmental parameters governing the functions.

These biological systems are stressed in the purification process since molluscs are not in their natural habitat. The stresses are particularly revealed in purification plants such as those in Massachusetts and New Jersey in which recirculated seawater systems are employed. In recirculation systems, seawater temperature may rise, dissolved oxygen usually drops, metabolic wastes build up, and pH drops. Turbidity was a significant factor in design of the referenced hard clam pilot plant in New York. Because of this factor, exploration for saltwater wells was begun. The lack of food in well water is a major problem and the food factor has not been entirely answered. However, soft and hard clams in the United States have been successfully purified in water provided from wells which have little available food.

The literature is replete with quantitative research on the effects of these environmental factors on the physiology of molluscs. Their practical relation to purification has been discussed by Cabelli and Heffernan (1970), Furfari (1966), Goggins *et al* (1964), Heffernan and Cabelli (1970 and 1971), Presnell, Cummins and Miescier (1969),

TABLE II
BIOLOGICAL ASPECTS OF SHELLFISH PURIFICATION

Major biological system	*Function*	*Purification process considerations*
1. Excretory	(*a*) faeces production	Sea water should contain food to enhance purging of gut
	(*b*) pseudofaeces production	Turbidity factor
	(*c*) diapedesis	A factor in eliminating pathogens from the blood stream
2. Nervous	(*a*) detection of adverse environment	Proper temperature, salinity, dissolved oxygen, pH, to maintain overall activity
	(*b*) hibernation	Occurs with adverse environment
3. Respiratory (gills)	water transport	Dissolved oxygen levels. Low turbidity to prevent gill clogging
4. Musculoskeletal (adductor muscle and ligament)	shell opening and closing	Proper stacking of shellfish in baskets
5. Reproductive	spawning	Immediately after spawning, shellfish may not be active enough to purify. Spawning is induced by rapid temperature rises

and Wood (1961). An excellent overall view of biology of shellfish with emphasis on oysters has been published by Galtsoff (1964).

Despite all that is known about the biology of molluscan shellfish, no reliable biological or physiological phenomena quantitatively demonstrate successful purification of pathogenic micro-organisms. It is merely presumed that a large population of molluscs in a tank are active and purifying if shells open and close, faeces and pseudofaeces are produced, or dissolved oxygen drops, and, in general, things appear normal. The only way to assure or demonstrate that purification has taken place is by the use of bacterial indicator systems.

4.2 *Bacterial reduction*

Since the turn of the century, much research has been done on bacterial purification for oysters, clams, and mussels. The majority of the work has involved coliform bacteria, *ie*, total coliform group, faecal coliform, or *Escherichia coli*. Only limited data are available for Salmonella, Shigella, and marine flora.

In order to show how bacteriological criteria for purification of molluscs in the United States were developed, it is appropriate to review some of the research along these lines.

The coliform data reveal species differences in rates of purification. For example, the American oyster, *Crassostrea virginica*, may reduce quite high levels of coliform to indeterminately low levels in 24 hours, while the soft clam, *Mya arenaria*, is quite slow in reducing levels. Typical values for this oyster are given by Huntley and Hammerstrom (1971). Zero-hour values (time at which the purification process begins) in the realm of 1 700 faecal coliform/100 g typically reduced to 18/100 g in 48 hours. Zero-hour values in the range of 49 000/100 g reduced to 18/100 g in 72 hours. Different experimental set-ups, of course, produced different reduction rates. Presnell, Cummins and Miescier (1969) showed 99·9% reductions of *E. coli* in 24 hours starting with values in the realm of 10^7 *E. coli*/100 g. Wood (1961) showed for the European oyster, *Ostrea edulis*, rather consistent 99% reductions of *E. coli* to indeterminable values in 48 hours.

Heffernan and Cabelli (1970) showed for the hard clam, *Mercenaria mercenaria*, 99·99% reductions in *E. coli* in 48 hours, and non-detectable levels of *E. coli* after 24 hours when zero-hour values were less than 104/100 g.

Data by Goggins *et al* (1964) on the soft clam, *Mya arenaria*, generally revealed 90% reduction in 24 hours. The data did not demonstrate a rapid decline in bacteria in the first 24 hours as indicated for oysters and hard clams. The Cabelli and Heffernan (1970) data for soft clams did show more rapid reductions, however.

Heffernan and Cabelli (1971) recommend target (or purified) levels of 25 faecal coliform/100 g at 48 hours of purification. This imposes a ceiling level at zero-hour for soft and hard clams of about 2 000 organisms/100 g. The inter-relationships of zero-hour bacterial level, time for purification, and target or finished product level are interesting from the point of view of what public health officials will allow. In Europe, there are no specified zero-hour values, yet for one locality in the United States, there are such values. Furthermore, the allowed zero-hour value is automatically set by an allowable water quality despite species differences in ability to accumulate sewage bacteria. Section 5 on monitoring and controls provides the standards used in the United States.

4.3 *Viral depuration*

Inability to monitor viral depuration has possibly held back the use of the process for some species in many localities in the United States. Several good works on viral depuration are available in research literature. Not only are they valuable with regard to viral depuration *per se*, but they are important from the aspect of the attainment of the perfect or ultimate purification process. This relates to the complete purging of all microbial contaminants and the optimization of environmental parameters needed to control the process.

To partially compensate for the inability to study hepatitis virus, research has been conducted on oysters (*Crassostrea virginica, Ostrea edulis*), hard clams (*Mercenaria mercenaria*), and mussels (*Mytilus edulis*), using polio, coxsackie, and ECHO viruses. Generally speaking, viral accumulation and depletion rates follow that of coliform for the species studied, *ie*, sometimes virus was present at 24 or 48 hours or longer depending on initial levels and other experimental factors.

Hamblet *et al* (1969) showed that oysters (*Crassostrea virginica*) purified themselves of poliovirus in 48 hours, from greater than 10^3 Plaque Forming Units (PFU)/ml to non-detectable (<0·2/ml) despite turbidities as high as 80 mg/l. Mitchell *et al* (1966) also showed rapid elimination of poliovirus from oysters at rates paralleling that of *E. coli*.

Liu, Seraichekas and Murphy (1967) demonstrated that the hard clam (*Mercenaria mercenaria*) could be purified of poliovirus at varying removal rates depending on temperature, salinity, and initial pollution levels. Some interesting questions brought up by these studies include: What initial levels of viral pollution are to be depleted? Do artificially polluted shellfish really simulate natural conditions? What pitfalls are there in experimental systems that cannot be foreseen for commercial size plants? Liu, Seraichekas and Murphy (1967) also raised the possibility that the poliovirus–shellfish interaction is not the same as that for hepatitis virus.

The crux of the matter, as they pointed out, is the initial level of virus in the molluscs. The fact that virus can be removed is not at issue any longer. The initial level of virus and its effect seem to be analogous to the initial level of bacteria. The initial level of virus relates to epidemiology of the pollution source and the subsequent die-off and dilution in the sea water.

5 Monitoring and controls

As with any food process, there is a need to know that the process itself is working and that the product is safe for human consumption. Monitoring and control over the water by sampling are, therefore, required. The shellfish must also be sampled in an orderly manner.

In the United States, recommendations call for bacteriological sampling of water in the harvest areas, the untreated process water, the treated water, and tank water at the plant. As data accumulate to establish a norm, the continued sampling will reveal problems as they arise. Attempts can be made to relate a poor finished product with evidence of poor water quality during the time a particular lot of shellfish was purified. Other water samples are taken for

analyses of turbidity, salinity, and dissolved oxygen to determine if these factors were responsible for the poor product.

Shellfish sampling is required to determine if purification has taken place as evidenced by reduced bacterial levels, and if guidelines for the finished product are met. Although there is no official federal standard in the United States, the general guideline for the soft clam, *Mya arenaria*, is a median value of 50 faecal coliform/100 g of meat by a most probable number (MPN) tube liquid broth technique or by an elevated temperature plate test on modified MacConkey's media. In England, the allowed level of bacteria for *Ostrea edulis* is five *E. coli* colonies/ml of meat using a MacConkey's media, which is approximately ten times the guideline level in the United States.

Sampling frequency is not standardized in the United States, but it is left to the discretion of the health departments of the individual states. In Massachusetts, an elevated temperature plate test using a modified MacConkey's media is used since results are available in 18–24 hours (Heffernan and Cabelli, 1970). If a zero-hour value for *Mya arenaria* exceeds 1 600 colonies/100 g, the harvest area is immediately closed. If a zero-hour value falls between 1 000–1 600 colonies/100 g, another sample is taken after 24 hours of purification; if the 24-hour value is less than 500 colonies/100 g, the shellfish are released at 48 hours. If the 24-hour value is greater than 500 colonies/100 g, another sample is taken at 48 hours, and the shellfish are purified for an additional 24 hours. Shellfish are sampled at the plant at zero-hour. Only a few routine 24- or 48-hour samples are taken. Thus, it can be seen that emphasis is on good control over the harvest areas from which the shellfish are taken.

In Maine, several small plants are monitored by taking weekly zero-, 24-, and 48-hour samples on certain lots. There are no limits on zero-hour values of faecal coliform by the MPN liquid broth method. However, the harvest area is carefully controlled by water sampling. The water in the harvest area rarely exceeds 700 total coliform/100 ml—about equivalent to 140 faecal coliform/100 ml.

In New Jersey, shellfish sampling emphasis is on the finished product: but again, the harvesting areas are carefully monitored by water sampling to assure that the median total coliform does not exceed 700/100 ml. When a plant starts anew, five sub-samples of shellfish are taken at 0, 24, and 48 hours for each lot. After several months of this heavy sampling, the sub-samples are reduced to two, three, and five at 0, 24, and 48 hours, respectively.

Raw and untreated water samples are taken in all plants on either a weekly or daily basis depending on circumstances. Temperature and salinity are measured daily. Dissolved oxygen is monitored in Massachusetts and New Jersey because the water is recirculated.

6 Review of current designs and operations

The purpose of this section is to present some fundamentals of current designs and to describe how existing plants deviate from these fundamentals with subsequent problems.

6.1 *Plant site*

The site of a shellfish purification plant is of fundamental importance as it governs the design and layout of the structure, and thus governs internal operations, such as product flow. The most important factor in the site is a suitable supply of sea water for the shellfish. The site should be located where fluctuations in salinity are minimal; if this is not possible saltwater wells should be considered. Another important consideration is sewage pollution and whether extraordinary disinfection is required. The factors of temperature, turbidity, and dissolved oxygen are discussed later. The sea water should not contain industrial pollutants which may contaminate the shellfish.

Another factor in site selection is the suitability of a seawater intake and a discharge outfall. Poor planning will lead to operating problems associated with reliable pumping over all tides.

The plant in Massachusetts must operate on the tide simply because of poor plant siting. It is located on a river with a large tidal range of about 3 m. On low tide the salinity of the river is too low for effective purification; also on low tide, the coliform level is much higher than desired. Thus, the plant can only pump water on high tide when the saltwater wedge reaches the seawater intake. As the time of high tide advances one hour each day, the plant's operations also advance one hour. This feature affects shellfish delivery, monitoring, timing, ability to handle large numbers of shellfish (wash and cull) and pumping. This has resulted in many logistic problems when the pumps have failed at a critical time.

Saltwater wells are not always appropriate despite their utilization in Maine and New York. An oyster purification plant in Delaware encountered problems with hydrogen sulphide in the water with the accompanying sulphide odour tainting the shellfish. The plant had to change to the more polluted surface water supply. The saltwater wells in Maine are about 2 m deep, but the one in New York was about 40 m deep.

6.2 *Plant structure*

The physical structure of plants in the United States is varied. Most are wooden structures with shingled roofs. Generally, concrete floor slabs with drainage channels or traps are used. Some plants have been made by converting shucking houses or lobster pools. There is no standardized design for purification plants. There are, however, regulations governing sanitation of structures containing shellfish with regard to adequate wash water, cleanability of walls, floors, and equipment, animal and pest control, and adequate toilet facilities with sewage disposal.

An all-indoor plant is not mandatory but in cold weather climates the need is greater. Electrical equipment needs to be protected against wet weather and the subsequent corrosion and hazards. So far, all plants in the United States have had all components under a roof. However, in some plants in Europe, components such as depuration or water treatment tanks are outdoors and other parts are indoors. There is no absolute rule about this.

6.3 *Plant layout*

The current idealized plant layout is given in Fig. 1. The major point is separation of the purified from the unpurified shellfish; however, efficiency and ease of product flow are important considerations.

This type of layout was basically attained at the large soft clam plant in Maine since it was constructed as a purification plant. However, none of the existing plants or the former pilot plants in the United States were

constructed using the concepts of this layout. All of these plants were converted structures; *eg*, lobster pools, wet storage areas, garages, shucking houses.

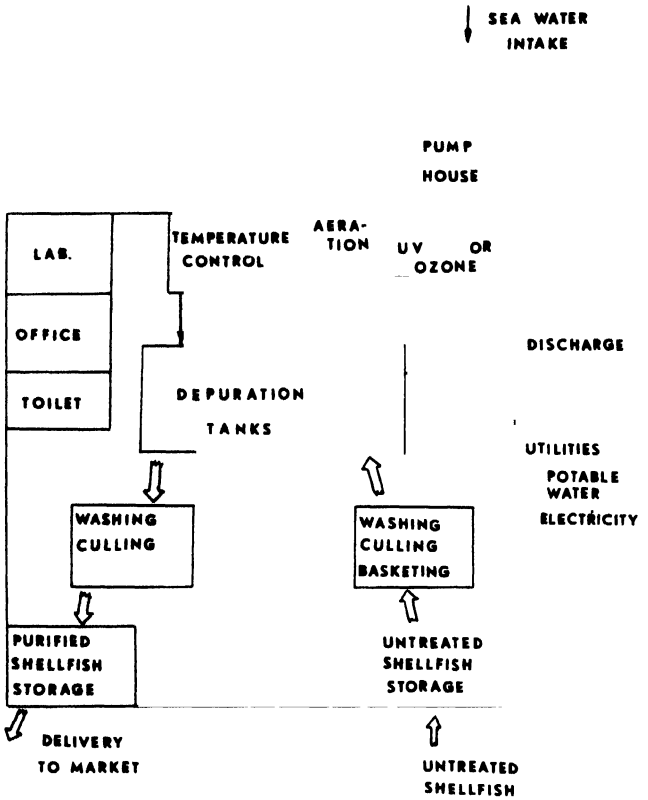


Fig 1. Schematic of a shellfish purification plant

6.4 *Shellfish handling*

The larger plants in the United States use tote carts to handle large lots. However, the pilot operations in Maine used overhead trolleys with chainfall and pallets and the oyster plant in Delaware used conveyor belts.

The shellfish are ordinarily placed into appropriate baskets which do not inhibit proper water flow in the purification tanks. *Crassostrea virginica* and *Mercenaria mercenaria* are not placed in layers or in baskets over 8 cm deep. *Mya arenaria*, from experience, is allowed in baskets about 20 cm deep. Baskets currently used are made of wood with galvanized wire mesh, plastic-coated expanded metal or plastic-coated wire mesh. Dimensions are approximately 45 x 90 cm, but this has varied with individual circumstances and availability.

The large soft clam depuration plant in New Jersey uses plastic mesh bags. These have proven economically feasible and have not caused any insurmountable problems with the depuration process or with breakage.

6.5 *Seawater systems*

Plastic pipe is recommended for seawater systems in the United States. This eliminates the corrosion problem caused by sea water, and also minimizes any problems with materials which could be toxic to both shellfish and humans. Experience has shown that seawater systems for purification plants should be engineered in advance to prevent operational problems. The practice of haphazardly putting together seawater systems has invariably resulted in malfunctions. Problems encountered include: poor pump priming, growth of marine life in piping systems that cannot be cleaned; and poor valving such that flow balancing among tanks and treatment units is impossible.

6.6 *Water treatment and environmental levels*

The most important aspect of purification is assurance that shellfish receive process water comparable with their biological systems and that the shellfish do not become contaminated in that water. Each of the parameters of water quality is subject to species and geographic differences. Although it is the responsibility of the official control agency or purification plant operator to experiment and find the best levels for these parameters, general ranges may be promulgated to be used nationwide in the absence of experimentation. These are given in Table III (Furfari, 1966).

TABLE III
WATER-QUALITY PARAMETERS FOR PROCESS SEA WATER

Parameter	*Minimum*	*Maximum*
Temperature	10°C	20°C
Dissolved oxygen	5·0 mg/l	Saturation
Turbidity	—	20 JTU[1]
Salinity	Within 20% of the value at the harvest area	

[1] JTU = Jackson Turbidity Units as defined by the Candle Turbidimeter

All of the plants in the United States have experienced variable water quality causing them to use some form of treatment.

The plants in Maine require heat exchangers in the winter to raise water temperatures for soft clam purification. The plant in New Jersey must cool the water in summer and heat it in winter. The recent New Jersey requirement is for a minimum temperature of 4°C for soft clams.

The recirculating seawater systems in the United States and United Kingdom take into account the need for aeration. The general principle is a cascading or splashing. However, the Massachusetts soft clam plant utilizes both a timed air bubbling system and a splashing system by distributing the water over the surface of the tank.

In a flow-through seawater system, the general criterion for all species of shellfish is a flow rate of 105 l/min/m^3 of shellfish (Furfari, 1966). This generally assures that the dissolved oxygen level will not be below 5 mg/l.

There are no plants in the United States requiring salinity adjustments; however, because shellfish are expected to be active almost immediately upon the start of the purification process, the salinity of the process water is expected to be close to that of the harvest area. According to experimental data (Goggins *et al*, 1964; Heffernan and Cabelli, 1970; Furfari, 1966) salinity of the process water should not vary by more than 20% of the salinity of the harvest site. Furthermore, minimum salinity values of 22‰ for *Mercenaria mercenaria* (Heffernan and Cabelli, 1970) and 20 ppt for *Mya arenaria* (Cabelli and Heffernan, 1970) have been recommended. Purification rates for *Crassostrea virginica* were significantly reduced with salinities below 7 ppt (Presnell, Cummins and Miescier, 1969). The purification rates were better, however, when salinity was over 16‰.

6.7 *Water treatment for microbials*

In order to maintain sanitary conditions and to assure that the water used in purification is not contaminated, treatment of microbiological contamination is necessary. Pollution creates the need for depuration, and because it is more economical to locate the purification plant near the polluted harvest area, the source of process water is usually contaminated with pathogenic organisms derived from sewage. To avoid recontamination it is necessary to destroy the pathogens. This aspect of the process is very important.

Historically, the methods have involved chlorination, ozone, and UV light. Chlorination has been criticized because of the effects of the chlorine residue on the sensitive shellfish tissue. Chlorination followed by dechlorination with sodium thiosulphate had been used in the past in Europe but has been discontinued in recent years in France. Within the past 15 years, ozone and UV light have generally supplanted chlorination.

In France and Spain, several shellfish purification plants use ozone to sterilize the sea water. Ozone is well known as a powerful oxidizing agent capable of rapidly killing bacteria and viruses. One advantage of ozone over chlorination is that less time is needed for purification of the shellfish; in water, ozone rapidly dissipates to dissolved oxygen, while chlorine residue remains and affects the sensitive tissue of shellfish. It has been reported that shellfish purified in water treated with ozone have a longer shelf life (Institute of Marine Fisheries, 1974). Ozone was used for purification of sea water as early as 1929 (Violle, 1929). Detailed ozone requirements have been worked out by experiments at Sète, France (Institute of Marine Fisheries). For example, if water contains 2 000–5 000 *E. coli*/l, 1·50–2·10 g/m^3 of ozone is required to assure sterilization of sea water; 1 000–2 000 *E. coli*/l requires 1·15–1·50 g/m^3; 250–1 000 *E. coli*/l requires 0·75–1·15 g/m^3. Ozone is also very effective in reducing the number of viruses, and much information on this property has been published in recent years (Rice and Browning, 1975).

UV light is used in the United Kingdom and United States in commercial plants. Its use as a disinfecting method for drinking water has long been known and numerous references are available on its effect on specific microorganisms. However, experiments on its specific use in shellfish purification plants are relatively few. Significant studies include its use for *Ostrea edulis* in England (Wood, 1961), and for *Crassostrea virginica* (Kelly, 1961) and *Mya arenaria* (Goggins *et al*, 1964) in the United States. The effective penetration of UV light is limited by depth of water and turbidity which must be considered in design of seawater systems. Applications to sea water of commercially available units designed for clear drinking water may not be appropriate. The aspect of flow rate versus turbidity and their effect on survival of poliovirus in sea water under UV light has been studied (Hill, Hamblet and Akin, 1967). The authors recommended constant vigilance of turbidity of sea water for UV treatment units. By reducing the flow rate (increasing time of exposure) with rising turbidity or vice versa, effective disinfection of viruses can be achieved. Because of the many variables involved with design of UV systems, actual design criteria are not given in this paper. However, Table IV delineates the variables, their effects on design, and how they are inter-related.

Wood (1961), Kelly (1961) and Goggins *et al* (1964) provide detailed design figures which are useful for commercial applications.

6.8 *Purification tank design*

There are no standardized purification tank designs in the United States, but adherence to basic concepts will assure sound hydraulics and sanitation. These are: (*i*) uniform hydraulic flow throughout the tank; (*ii*) proper stacking of shellfish baskets or containers to minimize hydraulic short-circuiting; (*iii*) cleanability and maintenance; (*iv*) the prevention of disturbance of shellfish by vibrations, turbulence, *etc*; (*v*) the prevention of contamination of shellstock.

These matters relate to size, depth, shape, materials of construction, and inflow-outflow piping arrangements.

In the United States, several materials have been used successfully: concrete; lining with epoxy paint; marine plywood coated with fibreglass; and prefabricated fibreglass tanks. These generally provide strong tanks with smooth non-porous surfaces for ease of cleaning.

Active soft clam plants in the northeast part of the United States have tanks with a variety of dimensions. For example, one plant has 54 small converted wooden lobster tanks, 1·2 × 2·43 × 0·4 m deep, which are stacked in tiers of three above floor level. Another plant has four large concrete tanks, 1·52 × 5·1 × 1·54 m deep, in which the tanks are abutted with a common wall 20·4 cm thick and are located partially below floor level.

The recommended physical features for new tanks in the USA would provide a maximum depth of about 0·9 m; a minimum space between baskets about 8 cm; a bottom slope of about 2% for quick drainage; a tank capacity of 4 000 l of water/m^3 of soft clams and 6 400 l/m^3 of hard clams and oysters.

In the United Kingdom (Wood, 1961) a certain degree of standardization exists. Two tanks holding 10 000 oysters (*Ostrea edulis*) are 6·1 × 1·53 m and 0·51 m deep holding 540 oysters/m^2. Materials may be concrete or wood. For smaller plants, prefabricated tanks of asbestos-cement are recommended in sizes up to 1·12 × 0·97 m to hold 660 oysters. Such small tanks can be combined and, depending on production rate, the system can be easily expanded.

TABLE IV
DESIGN PARAMETERS FOR ULTRAVIOLET TREATMENT UNITS

Size of plant	The number of treatment units is a function of the number of shellfish, and the number of tanks.
Flow rate	The flow rate allowed through a particular unit depends on water quality and dimensions of the unit. The number of shellfish affects the flow rate.
Water quality	High levels of bacteria in sea water require more treatment units, more electrical power for more UV lamps, more residence time, and consequently larger UV units. Turbidity has the same effect.
Seawater system	Flow-through systems will generally require more UV lamps than recirculating systems.

7 Contemporary research

7.1 *New and ongoing work*

Research on shellfish purification in the United States and elsewhere is at a low ebb. The federal government is sponsoring two projects: one relating to virus in the soft clam (*Mya arenaria*), the other to development of commercial parameters for the American oyster (*Crassostrea virginica*).

The virus work is basically a monitoring of an existing commercial soft clam purification plant in Massachusetts. Samples of zero-hour and final product at 48 hours are run for enteric viruses.

The oyster work is comprehensive and involves basic laboratory as well as commercial-scale work on purification rates with a wide variation in environmental parameters. This work is being done on oysters from Chesapeake Bay in Virginia. Although some of the work appears to be a repetition of that reported in the literature, there is a possibility of geographical differences. Some of the questions being answered concern the suitable ranges of the environmental parameters of these oysters. Temperature, turbidity, salinity, plankton density and condition index of the oyster have been studied. The influence of certain oyster diseases such as MSX and *Dermocystidium* have also been explored and in-depth studies of biodeposition have been carried out. Shellfish pumping rates have been correlated with rates of bacterial indicator depletion. Maximum permissible levels of bacteria are being determined and several large tank designs are being engineered to optimize flow rates and tank cleaning operations. Effects of waste products on the purification rate are also being studied. This project began in 1973.

In the United Kingdom some work is underway to purify hard clams in a new system of tiered trays but published reports are not available as yet (Personal communication, Peter Ayres, 1975).

As can be seen from the references, there was a peak of activity in the sixties, but the seventies brought a lull in research especially in the United States. The Canadians have done work on purification of oysters and clams in British Columbia and soft clams in Quebec and Nova Scotia. (The reports on these are not generally available and the results of the work have not yet been published.)

7.2 *Research needs*

The preceding section reveals the paucity of ongoing research on the purification process. Several questions must still be answered to provide assurances that the process is reliable or that it can be improved or made more rapid.

One basic need is a continuation of virus model studies in the laboratory to demonstrate how viruses may enter and leave the shellfish.

A complete interdisciplinary study of the process needs to be carried out to relate studies reported by bacteriologists and virologists to basic biology, engineering, or chemistry.

Effects of recirculating systems on artificial sea water should be studied in depth. Data are needed on the deterioration rate of sea water and efficient removal of metabolic waste products. The work of Allen *et al* (1950) should be continued with modern technology and treatment methods.

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Chapter V Culture of Algae and Seaweeds

Developments in the Culture of Algae and Seaweeds and the Future of the Industry

I. C. Neish

Abstract

Algae form all or part of the primary production base for many forms of aquaculture, but marine macrophytes are the algae most commonly cultured for direct utilization by man. Cultivation is an increasingly important means for producing algae, especially those used for human food and vegetable gum production. The Japanese and Korean *Porphyra* industries, the Chinese *Laminaria* industry and the Philippine *Eucheuma* industry are now primarily based on cultured raw material.

The commercial cultivation techniques described here include close management of natural stocks, live storage of harvested material, vegetative propagation of cultured crops, and grow-out of hatchery seed. Both labour-intensive and capital-intensive approaches are adopted, but all algal culture requires investment to permit control over seed stock, water supply, nutrients, pests, diseases, photic energy and thermal energy. Socio-economic constraints to algal culture development including competition for space with other industries, availability of labour, the benefits in some instances of establishing a vertically integrated marine plant industry, and the need for a developed legal framework concerning aquaculture, are important considerations affecting the algal culture industry.

It is suggested that increased utilization of algae and development of aquaculture can be expected to continue in suitable marine coastal areas throughout the world. As an aid to future development, continuing international co-operation is required to produce technical advances in areas such as: pest and disease control, genetics and seed stock selection, applied physiology, and dissemination of knowledge as research results and experience are accumulated.

Evolution de la culture des algues et autres plantes marines et avenir de cette branche d'activité

Résumé

Les algues constituent en totalité ou en partie la base de la production primaire de beaucoup de formes d'aquaculture, mais les plus couramment cultivées pour l'utilisation directe par l'homme sont les macrophytes marins. La culture est un système de production d'algues qui prend de plus en plus d'importance, notamment aux fins de l'alimentation humaine et de la production de gommes végétales. Les industries japonaise et coréenne de *Porphyra*, l'industrie chinoise de *Laminaria* et l'industrie philippine d'*Eucheuma* utilisent maintenant essentiellement une matière première cultivée.

Les techniques de cultures commerciales décrites ici englobent l'aménagement rigoureux des stocks naturels, l'entreposage *in vivo* du matériel récolté, la multiplication végétative des espèces cultivées et la culture de spores de pépinière. Les méthodes adoptées sont aussi bien du type avide de main-d'oeuvre que du type fortement capitalisé, mais toute entreprise de culture d'algues a besoin de fonds d'investissement pour qu'un contrôle puisse être exercé sur les stocks de spores, l'approvisionnement en eau, les éléments nutritifs, les ravageurs, les maladies, l'énergie photique et l'énergie thermique. Parmi les obstacles socio-économiques au développement de la culture des algues, citons: la concurrence d'autres industries pour l'occupation des lieux, les disponibilités en main-d'oeuvre, les avantages qu'il y a dans certains cas à mettre sur pied une industrie des plantes marines à intégration verticale et la nécessité de mettre au point un cadre juridique perfectionné pour l'aquaculture. Toutes considérations importantes qui affectent ce secteur.

On peut escompter, semble-t-il, que les utilisations des algues continueront à augmenter et l'aquaculture à se développer dans des zones littorales appropriées du monde entier. Pour aider l'expansion future, une coopération internationale ininterrompue sera requise aux fins du progrès technique dans des domaines tels que: lutte contre les ravageurs et les maladies; génétique et sélection des stocks de spores; physiologie appliquée, enfin diffusion des connaissances à mesure que s'accumulent résultats de recherches et expérience.

Progresos en el cultivo de algas y plantas marinas y futuro de esta industria

Extracto

Las algas constituyen la base total o parcial de producción primaria en muchas formas de acuicultura, pero las macrofitas marinas son las algas más comunmente utilizadas para uso directo por parte del hombre. El cultivo constituye una forma cada vez más importante de producción de algas, especialmente de las destinadas al consumo humano o a la producción de goma vegetal. Las industrias japonesa y coreana de *Porphyra*, la industria china de *Laminaria*, y la industria filipina de *Eucheuma* se basan hoy dia en materias primas cultivadas.

Entre las técnicas comerciales de cultivo descritas figuran el estricto control de el manejo de las poblaciones naturales, el almacenamiento en vivo de algas recogidas, la propagación vegetativa de plantas cultivadas, y la producción de semillas en viveros. Se utilizan tanto métodos que exigen un elevado coeficiente de mano de obra como sistemas que hacen necesarias grandes inversiones de capital, pero todos los cultivos de algas requieren ciertas inversiones para poder controlar las semillas, el abastecimiento de aguas, los nutrientes, las plagas y enfermedades, la energia fótica y la energía térmica. Entre los obstáculos socio-económicos que se oponen al desarrollo del cultivo de algas pueden mencionarse la competencia con otros sectores para poder disponer del espacio necesario, la disponibilidad de mano de obra, los beneficios que pueden obtenerse en algunos casos con el establecimiento de una industria de plantas marinas integrada verticalmente, y la necesidad de un marco juridico completo para la acuicultura.

Se sugiere que en las zonas marítimas costeras de todo el mundo que reunen las condiciones necesarias seguirá aumentando con toda probabilidad el empleo de algas y el desarrollo de la acuicultura. Para promover el desarrollo de esta industria en el futuro es necesario que prosiga la colaboración internacional para lograr progresos técnicos en sectores como el control de plagas y enfermedades, la genética y selección de semillas, y la fisiología aplicada y es preciso, además, difundir los conocimientos que se vayan acumulando como fruto de investigaciones y nuevas experiencias.

1 Introduction

Algae form all or part of the primary productivity base for most types of aquaculture, and especially mariculture. Phytoplankton and macrophytes utilize organic wastes, produce oxygen, and contribute to the food chain in many fish culture operations so that the culture of algae or the management of algal populations may be considered as an integral part of many forms of fish and shellfish culture. Algae are also used directly, however, in providing a valuable source of human food, animal fodder, crop manure, and raw material for the chemical and pharmaceutical industries.

This paper deals with those algae which are cultured for direct utilization. Emphasis is placed on marine macrophytes (seaweeds) since these are more actively cultivated and utilized to a greater extent than phytoplankton or freshwater algae.

2 Importance of algae and their culture to industry

2.1 *Algae serving as food, fodder and manure*

Algae are utilized as human food, animal fodder, fertilizers and soil conditioners in coastal areas throughout the world. The geographical areas of usage and approximate levels of utilization of 56 algal genera are shown in Table I. On a worldwide basis, the algae most intensively utilized for human food include *Porphyra, Laminaria, Undaria, Hijikia* and *Rhodymenia*. Algae used most intensively as fodder and manure include *Ascophyllum, Laminaria, Macrocystis, Nereocystis* and *Sargassum*. Most algae can be utilized as manure, however, and in many parts of the world mixed seaweed is removed from beaches and placed on fields.

The value of algae as human food has been assessed in

TABLE I

GENERA OF ALGAE USED AS FOOD, FODDER OR MANURE, THEIR UTILIZATION LEVEL AND MAJOR GEOGRAPHICAL REGIONS OF PRODUCTION. AFTER CHAPMAN (1970) AND JOHNSTON (1966)

1. Africa
2. Australia/New Zealand
3. Asia (west and southeast)
4. Asia (China, Russia)
5. Asia (Japan)
6. Europe
7. North America (east)
8. North America (west)
9. Pacific Oceania
10. South America and Caribbean

Genus (class)[1]	*Utilization level*[2]	*Geographical region*									
		1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*
Acanthopeltis (R)						×					
Acanthrophora (R)				×							
Agardhiella (R)*				×							
Alaria (P)*	+					×	×	×	×		
Arthrothamnus (P)						×					
Ascophyllum (P)*	++						×	×			
Asparagopsis (R)										×	
Campylaeophora (R)						×					
Carpopeltis (R)						×					
Caulerpa (R)	+			×							
Chaetomorpha (C)				×							×
Chlorella (C/Fw)*					×						
Chondrus (R)*	+				×	×	×	×			
Codium (C)				×	×	×				×	
Corallopsis (R)				×							
Dictyota (P)				×						×	
Durvillea (P)			×								×
Ecklonia (P)	+				×	×					
Eisenia (P)	+					×					
Enteromorpha (C)*	+			×	×	×	×	×			
Eucheuma (R)*	++			×	×	×					
Fucus (P)							×		×	×	
Gelidiopsis (R)				×							
Gelidium (R)					×	×				×	
Gigartina (R)*	+					×	×	×	×		
Gloiopeltis (R)				×							
Gracilaria (R)*	+			×	×	×	×			×	
Grateloupia (R)				×	×	×				×	
Griffithsia (R)					×						
Gymnogongrus (R)				×		×				×	
Halliseris (P)										×	
Heterochordaria (P)						×					
Hijikia (P)*	++					×					
Hypnea (R)*	+			×						×	
Iridaea (R)*	+						×		×		×
Laminaria (P)*	++				×	×	×	×			
Laurencia (R)				×			×			×	
Macrocystis (P)*	+		×						×		
Mesogloia (P)					×						
Monostroma (C)*	+				×	×	×				
Nemalion (R)					×						
Nematonostoc (Cy/Fw)	+			×							
Nereocystis (P)	+								×		
Nostoc (Cy/Fw)	+			×							
Padina (P)			×								
Petalonia (P)						×					
Phyllogigas (P)											×
Porphyra (R)*	++		×		×	×	×	×	×		
Rhodymenia (R)*	++				×		×	×	×		
Sarcodia (R)				×		×					
Sargassum (P)	+			×	×	×					
Spirulina (Cy/Fw)*		×									
Suhria (R)		×									
Turbinaria (P)				×							
Ulva (C)*	+				×	×	×				×
Undaria (P)*	++				×	×					

* Genera for which commercial cultivation is practised or is being developed

[1] Symbols in brackets () denote algal classes: (C) Chlorophycophyta; (Cy) Cyanophycophyta; (P) Phaeophycophyta; (R) Rhodophycophyta; with the exception of symbol '/Fw' which denotes freshwater algae

[2] '+' denotes common utilization, and '++' denotes intensive utilization

Japan, China and Europe. Cheng (1969) pointed out that *Laminaria* is regarded as a valuable food source in China, and evidence cited by Chapman (1970) indicates that most food algae serve as a useful source of minerals and of trace elements, while red algae, such as *Porphyra* and *Rhodymenia*, provide a source of assimilable carbohydrate and protein. Throughout history, marine plants have been particularly valued for their role as a source of iodine.

Chapman (1970) has reviewed much of the literature concerning uses of algae for fodder and manure. The detailed work of Jensen (1972) on *Ascophyllum* has pointed out the value of this seaweed as a feed supplement for pigs, cattle and other livestock. Seaweeds provide trace elements, minerals, roughage and carbohydrate to livestock, and some animals, such as sheep, can live entirely on a diet of seaweeds.

When used as manure, seaweeds act both as fertilizers and soil conditioners. Marine plants do not have a high nitrogen content but beneficial effects of seaweed application have been cited by a number of workers, particularly when they have been applied to sandy soils. Seaweeds are used effectively as manures for a wide variety of horticultural and agricultural crops including citrus fruits (Aitken, Senn and Martin, 1961), strawberries (Driggers and Marucci, 1964), and a variety of field crops (Booth, 1964; Milton, 1964).

Chapman (1970) and Okazaki (1971) have reviewed the uses of algae as human food. Most food algae are simply dried before consumption or may be eaten fresh. *Porphyra* is commonly fragmented before being dried in the form of sheets. These sheets may be treated with various spices and cooked. The most common use of *Porphyra* is as an ingredient in dishes, such as the Japanese sushi, in which portions of *Porphyra* (nori) sheets are wrapped around flavoured rice. Dried *Laminaria* serves as a component of soup stocks or may be eaten as a vegetable. It is consumed in large quantities in China and Japan, where it is called kombu. *Rhodymenia* (dulse) is consumed fresh or dried in a whole frond form, or may be reduced mechanically to powder and flakes for use as a condiment and as a component of pills. Many edible seaweeds are reduced to powder for use in tablets which are consumed primarily for their trace element value.

Seaweeds used as fertilizer and stock feed supplements are generally dried and ground to produce a meal or powder. Whole seaweeds may also be fed to animals or mulched into the soil. In Europe and North America, basic hydrolysis of seaweeds, such as *Ascophyllum, Macrocystis* and *Laminaria*, is carried out to produce liquid fertilizer extracts.

2.2 *Algae as sources of chemicals*

By weight, more than 50% of the harvested algae are used as raw material for the chemical industry. Until the first half of the twentieth century, large quantities of algae were burned in Europe and Asia to produce iodine and potash until more economical means were found for their production. The bulk of industrial seaweed utilization is now in the vegetable gum industry; 29 genera of seaweeds utilized in this industry are listed in Table II. The most important gums produced from these genera are agar-agar, carrageenan, funorin, furcellarin, and alginates. All but the latter class of gums are produced from red algae (class—Rhodophycophyta), while alginates are extracted from seaweeds of the class Phaeophycophyta. Most seaweeds utilized by the alginate industry are large forms, such as *Macrocystis, Nereocystis, Laminaria* and *Ascophyllum*.

Agar-agar has important food and medicinal uses, carrageenan is widely used in the dairy industry and alginates are used in a number of industrial processes related to textile sizing, and the production of synthetic rubber, adhesives, paper products, and pharmaceutical products. The major world centres for vegetable gum production are the northeastern and southeastern United States, western Europe, Japan, China and Russia. Although crude forms of agar-agar can be produced in simple factories, most forms of vegetable gum require elaborate production facilities and the industry tends to be centralized. For example, most carrageenan is produced by three companies in the USA, France and Denmark, and a large proportion of world algin and alginate production is concentrated in southern California.

2.3 *The importance of cultivation to the seaweed industry*

Aquaculture plays a very important role in the provision of raw material to industries utilizing algae. The Japanese *Porphyra* industry, which has a retail value of more than US$ 150 million per annum (Craigie, 1971), is almost entirely dependent upon cultivated sources of raw material from Japan and Korea. Cheng (1969) has reported that a substantial kelp industry has been established in mainland China based entirely on cultivation of *Laminaria japonica*, a species which was imported from Japan in the first half of the twentieth century. Present production of this industry is believed to be in excess of 100 000 tons per annum.

Close management of national stocks, commercial cultivation or development of culture techniques are being undertaken with a number of other algal genera (see Tables I and II). Within the past five years, cultivation in the Philippines has become an important source of *Eucheuma* for the carrageenan industry, and at least two of the three major world producers are developing cultivation techniques for *Chondrus, Gigartina, Hypnea* and *Iridaea*. The cultivation of agarophytes is a matter of great interest to investigators throughout the world and extensive commercial agarophyte cultivation can be expected in the near future. Besides being important to kelp production in China, aquaculture is an important producer of *Laminaria* in Japan, and kelp habitat improvement has been instrumental in reviving the southwest North American *Macrocystis* industry (North, 1976).

At present, virtually all intensively harvested populations of marine algae are closely managed or are cultivated over much of their geographical distribution. Algae are particularly well suited to cultivation because they are primary producers which can be grown in an attached or detached form, and production rates from cultures of algae equal or exceed yields from the most productive forms of terrestrial agriculture (Mann, 1972). Throughout the world, inadequate sources of supply or escalating labour and material costs for harvesting natural algal resources are stimulating the development of aquaculture techniques; outstanding successes have been observed in the *Porphyra, Eucheuma* and *Laminaria* industries.

3 Cultivation technology for algae

3.1 *Techniques used for culturing algae*

The cultivation of algae involves a range of techniques—as

TABLE II

GENERA OF ALGAE WHICH SERVE AS SIGNIFICANT SOURCES OF CHEMICAL PRODUCTS, AND MAJOR REGIONS FOR THEIR PRODUCTION. AFTER CHAPMAN (1970)

Key to geographical regions:

1. Africa
2. Australia/New Zealand
3. Asia (west and southeast)
4. Asia (China, Russia)
5. Asia (Japan)
6. Europe
7. North America (east)
8. North America (west)
9. Pacific Oceania
10. South America and Caribbean

Genus (product)[1]	*Geographical region*									
	1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*
Acanthopeltis (A)					×					
Ahnfeltia (A; Fu)				×						
Ascophyllum (Al)*						×	×			
Campylaeophora (A)				×	×					
Chondrus (C; Fu)*			×			×	×			
Ecklonia (Al)		×			×					
Eisenia (Al)					×					
Eucheuma (C)*			×				×			
Furcellaria (F)*						×	×			
Fucus (Al)						×	×			
Gelidiella (A)					×					
Gelidiopsis (A)			×							
Gelidium (A)	×					×	×	×		
Gigartina (C)*		×				×	×	×		
Gloiopeltis (Fu)					×			×		
Gracilaria (A)*	×	×	×	×	×		×	×	×	×
Grateloupia (Fu)					×					
Gymnogongrus (Fu)					×					
Hypnea (C)*	×					×	×			
Iridaea (C)*								×		×
Laminaria (Al; M)*	×			×	×	×	×			
Macrocystis (Al)*		×						×		×
Nereocystis (Al)								×		
Pelagophycis (Al)								×		
Phyllophora (A; M)				×						
Pterocladia (A)		×			×			×		
Sargassum (Al)					×					
Suhria (A)	×									

* Genera for which commercial cultivation is practised or is being developed

[1] Symbols in brackets denote major products extracted: (A) agar-agar; (Al) algin and alginates; (C) carrageenan; (Fu) funorin; (F) furcellarin; (M) minerals, such as iodine

simple as the management of natural stocks, or as complex as the propagation of selected clones and genetically-bred hatchery seed stock in capital intensive cultivation situations. Table III lists the genera of algae that are cultivated, and includes their cultivation techniques which are described below:

(*i*) Management of natural stocks. Management and husbandry of natural stocks is a first step toward aquaculture and is practised with most intensively harvested algal populations throughout the world. In Canada and Norway, for example, *Ascophyllum* harvesting is carefully controlled to allow sustained harvest, and intensive research is carried out to determine rates of regrowth from harvested beds. The same is true of *Chondrus* from eastern Canada, Great Britain and Spain. *Laminaria* is a cultivated genus, but carefully managed exploitative harvesting still yields

TABLE III

CULTURED GENERA OF ALGAE AND TECHNIQUES FOR THEIR CULTIVATION

Genus	*Cultivation techniques*				
	Management of natural stocks (i)	*Habitat improvement (ii)*	*Live storage of harvested plants (iii)*	*Vegetative propagation (iv)*	*Culture from hatchery seed (v)*
Ascophyllum	××		××		
Chlorella				×	×
Chondrus	××			×	
Eucheuma	××			××	
Gigartina	×			×	
Gracilaria	××	×		×	
Hypnea				×	
Iridaea			×		
Laminaria	××	××	××		××
Macrocystis	××	××			
Porphyra	××	××			××
Rhodymenia	×	×	××	×	×

Note: '×' denotes developing techniques, or techniques yielding small quantities of raw material
'××' denotes strategies which are currently used commercially on a large proportion of utilized raw material

significant quantities in western Europe and Japan. Efforts to regulate the *Macrocystis* harvest are particularly notable since harvestable stocks virtually disappeared off the California coast in the late fifties. The habitat improvement work of W. J. North plus careful management of harvesting by the industry have now resulted in recovery of an important source of alginates.

(*ii*) Habitat improvement. In his analysis of marine algal ecology, Chapman (1974) pointed out that marine macrophyte communities are complex systems in which desirable commercial species do not always prevail. This fact, and the difficulty of harvesting widely dispersed wild stocks, provided the initial impetus for seaweed plant culture. The earliest form of algal aquaculture was the addition of suitable substrate to areas which were not capable of supporting populations of commercially useful algae. For example, early forms of *Porphyra* cultivation in Japan, which started in 1736 at Tokyo Bay, consisted primarily of the addition of twigs and other types of substrate to muddy areas which did not provide suitable places for the attachment of this plant (Okazaki, 1971). Substrate addition to increase stocks of *Gracilaria* and *Eucheuma* has also been practised in tropical areas by spreading dead coral over predominantly sandy areas where these seaweeds cannot attach.

(*iii*) Live storage of harvested plants. Detached, live-harvested plants can be stored for periods varying from a few days to many months depending on the conditions provided. In the alginate industry, for example, live *Ascophyllum* is sometimes held in large ponds until it can be processed. *Rhodymenia* processors in eastern Canada hold live material in air-agitated tanks until suitable drying conditions are available or until harvested plants can be run through a mechanical dehydrator (Neish, 1976). In this industry, harvesting is carried out only during very low tides of the spring, summer and autumn so the flow of raw material through a processing facility is uneven and a capacity for holding live material greatly enhances processing efficiency. In holding tanks, the algae are cleansed of dirt, mussels, epiphytes and other contaminants. *Rhodymenia* also grows in storage tanks, and yields of over 60 g dry weight/m^2/day have been obtained in storage ponds stocked at a density of approximately 10 kg fresh weight/m^2.

(*iv*) Vegetative propagation of cultured algae. Some perennial algae can be vegetatively propagated in culture, and algae with a distinct sexual phase can be bred in hatcheries to provide seed. These two modes of reproduction provide two distinct approaches to obtaining seed stock for algal culture.

Vegetative propagation of wild stock in enclosures or attached to suspension materials is a logical extension of the live storage of harvested material. This technique may be commercially developed for species with annual fronds and perennial holdfasts, such as *Iridaea* and *Rhodymenia*, providing that means can be found for harvesting fronds and retaining holdfasts in culture. Commercial application, however, is emphasizing the propagation of perennial genera, such as *Chondrus* and *Eucheuma*.

Vegetative propagation of selected clones is a commercial reality in the Philippines, where various strains of *Eucheuma* are cultivated (Doty and Alvarez, 1975). Filippino culture techniques are labour-intensive and involve the manual attachment of fronds to lines or nets and continuous cropping back to maintain crop densities and produce the yield. Capital-intensive techniques with a low labour content are being investigated for vegetative propagation of carrageenophytes by Marine Colloids, Inc. of Rockland, Maine, USA, and Kobenhaven Pektin Fabrik of Denmark. The techniques being developed by these companies are based on initial work carried out at the National Research Council of Canada by Neish and Fox (1971) and by Shacklock *et al* (1973), and involve the propagation of macrophytes (*eg*, *Chondrus*) in detached form in agitated ponds or tanks. This form of macrophyte culture resembles the cultivation of unicellular organisms in the fermentation industry or cultivation of unicellular algae for feeding to molluscs. Although still in its development stage, this technique is under active commercial development and is expected to produce significant quantities of *Chondrus* within the next five years. This system is also being considered for culture of *Eucheuma*, *Gigartina* and *Hypnea*.

The selection of fast-growing clones with desirable characteristics is an important aspect of culture techniques utilizing vegetative propagation, and has contributed to the high productivity of *Eucheuma* farms in the Philippines (Doty and Alvarez, 1975). Development work with *Chondrus* has shown that selected strains of seed stock grow two to three times as fast as mixtures of wild stock. Clone selection will continue to be an important aspect of vegetative propagation procedures for algae farming.

(*v*) Cultivation of algae from hatchery seed. Two very important seaweed culture industries, the *Porphyra* industry of Japan (Okazaki, 1971), and the *Laminaria* industry of China (Cheng, 1969), are largely based on the cultivation of plants produced from hatchery seed. In these forms of cultivation, seed is attached to nets, ropes and a variety of other suspension materials before being placed in the sea for grow-out to commercial size. In North America, preliminary investigations are underway by carrageenan producing companies to determine whether the seed of hatchery-produced macrophytes can be grown economically in a detached form in agitated culture tanks. This form of cultivation would be useful for sexually reproduced annual plants of commercial significance.

Centuries of experience in agriculture have conclusively demonstrated the desirability of propagating selected strains rather than wild stocks. This has also proved to be the case with seaweeds, and in China fast-growing *Laminaria* strains, such as Hai-Ching No. 1, have increased yields according to Cheng (1969). Such techniques are applicable to any sexually reproducing alga of commercial interest and can be expected to become prevalent as algal cultivation develops. Propagation of selected strains has been practised for many years with planktonic algae, such as *Chlorella*, and various other algae serving as food for oysters and other shellfish. There are also preliminary studies underway in the United States to determine whether unicellular carrageenophytes can be cultured.

3.2 *Socio-economic and legal constraints*

The major socio-economic and legal constraints likely to affect the cultivation of algae are as follows:

(*i*) Marine plant cultivation, which comprises the major component of the algae culture industry, must compete for shore frontage and protected water space with several other industries. Navigational needs, the needs of other fisheries and aquaculture operations, needs of the lumber industry

and effects of pollution, all play a part in restricting the global areas available for marine plant cultivation. The same constraints apply for much of the freshwater cultivation of algae.

(*ii*) Selection of techniques for cultivation of algae will depend on the socio-economic structure of the region in which they are to be carried out. In some areas, such as southeast Asia, there is a long growing season, ready availability of labour in coastal areas at low cost, and a low enough cost of capital equipment to encourage the development of labour-intensive, low-capital investment marine plant culture techniques. In other areas, such as North America and Japan, such practices are becoming progressively less attractive, and the cultivation of algae can be expected to develop along capital-intensive lines which require sophisticated technology and a small labour content.

(*iii*) Some marine plant industries, such as the vegetable gum industry, are most efficient and most profitable if they are vertically integrated. This may tend to concentrate cultivation development of phycocolloid-bearing algae to areas capable of supporting technologically sophisticated extraction plants which have access to markets and marketing organizations.

(*iv*) All forms of marine plant aquaculture require significant investment in either capital or labour costs, and represent an intensive utilization of foreshore and nearshore waters. Algae must, therefore, be cultivated in countries with a well developed legal framework to protect aquaculture interests, and a stable political and economic environment.

3.3 *Elements of the culture of algae*

At present, virtually all forms of the cultivation of algae are either labour-intensive or capital-intensive. Regardless of which cultivation technique is used, however, the basic elements of algal aquaculture remain the same. These are depicted in Table IV.

Natural organic and inorganic energy and materials are the basic requirements for culture of algae. These include dissolved nutrients and gases, and solar radiation which provides photic and thermal energy. Seed stocks are also needed to initiate culture. Diseases, pests and contamination can significantly affect algal production. These basic elements of algal cultivation are manipulated or controlled to varying degrees as described below:

(*i*) Invest in capital equipment which transports and modifies natural energy and materials. In capital-intensive forms of cultivation, such as the growth of detached carrageenophytes, plants may be held in agitated enclosures and ponds which require a significant investment. In labour-intensive techniques, algae may be attached by hand to rafts

TABLE IV

THE MANIPULATION OF NATURAL ENERGY AND MATERIALS THROUGH ACTIVITIES INVOLVING THE USE OF CAPITAL AND LABOUR IN AN ALGAL AQUACULTURE ENTERPRISE

Activities involving the use of capital and labour	*Organic energy and materials*		*Inorganic energy and materials*		
	Seed stock	*Contaminants, diseases and pests*	*Water, dissolved nutrients and gases*	*Solar radiation*	
				Photic energy	*Thermal energy*
1. Invest in capital equipment which transports and modifies natural energy and materials	Enclosures, ponds, buildings, substrate, rafts and other suspension materials	Filters and sterilizers	Water distribution system and equipment for fertilizer provision	Electric lights, reflectors and shades (to control weed growth)	Heaters, coolers, thermal effluent
2. Purchase and apply consumable materials; purchase energy, materials and labour for maintenance and operation of equipment	Materials, energy and labour to maintain enclosures, substrate and suspension materials	Filtration materials, pest control agents, water treatment materials, energy and labour for pest and contaminant control	Energy to pump water; materials and labour to maintain distribution system	Light bulbs, maintenance materials and energy to operate and maintain lights or shades	Materials and energy to operate and maintain heat exchangers, valves, heating plants or refrigeration units
3. Conduct applied biological research to develop crop control and management techniques	Genetics, clone selection, population biology, ecology, phytosociology	Pathology, microbiology, mycology, biochemistry, herbivore control	Nutritional physiology	Physiology of photosynthesis and respiration	Physiology
4. Monitor crop and culture conditions; control use of energy and materials to achieve optimal benefit:cost ratio	Control population structure by monitoring and regulating harvest rates, density, distribution pattern, *etc.*	Monitor and control levels of pests and contaminants	Regulate water flow and fertilizer rates to get optimal cost:benefit ratio	Control light intensity, quality and duration if possible	Monitor and control water temperature
Cultured algae biosynthesize the desired end products					
5. Harvest, process and market the yield; maximize efficiency or profitability by regulating aquaculture farm production to suit market structure to as great an extent as possible	Regulate harvest rate to maintain optimal population structure and density	Integrate harvest regime with pest control levels to suit market demands	Integrate harvest techniques and water management	Manipulate access to light to 'finish' the product before harvesting	Manipulate temperature as an aid to 'finishing' or storing end product

(as in Chinese kelp culture) or to strings and nets (as in southeast Asian *Eucheuma* culture). Other investments in capital equipment may include: filters and sterilizers to control pests and contaminants; water distribution systems and equipment for fertilizer provision; electric lights and reflectors to increase growth rates during some stages of cultivation; the provision of shades to control weed growth on the sides of enclosures; and the provision of heaters and coolers to allow manipulation of water temperatures. All of these control techniques are utilized for the production of hatchery seed in the *Porphyra* industry, and they are being investigated for application to capital-intensive carrageenophyte cultivation.

(*ii*) Purchase and use of consumable materials, such as energy, materials and labour for maintenance and operation of equipment. No matter which cultivation strategy is used, labour and materials must be invested to maintain capital equipment for each phase of the operation. In capital-intensive cultivation, operational costs may become significant, especially if electrical energy is necessary for water pumps, lights, adjusting water temperatures, maintaining the crop in suspension and sterilizing the water.

(*iii*) Conduct applied biological research to develop crop control and management techniques. Cultivation of algae has benefited greatly from the application of scientific techniques to its development and genetics; clone selection, population biology, ecology and phytosociology have all been successfully applied, as in the cultivation of *Porphyra, Laminaria* and *Eucheuma*.

In algal cultivation, as in all other forms of intensive culture, pathology, microbiology, mycology and other disciplines related to pest and disease control are extremely important. Algae effectively concentrate heavy metals and other chemical components, so an awareness of water quality is essential as well.

Study of nutritional physiology is necessary since fertilization is used in the cultivation of algae. Natural nitrogen levels are inadequate for intensive cultivation in most sea water, so nitrogen fertilizers are used in the *Porphyra* and *Laminaria* industries. Economic utilization of fertilizer is also becoming increasingly important as fertilizer prices increase. In China, the ratio between nitrogen fertilizer and kelp production varies between 1:1 and 1:3·75, depending on the culture technique used (Cheng, 1969).

All phases of algae culture require a knowledge of plant physiology since the processes of photosynthesis and respiration must be well understood before the crop can be adequately managed. Knowledge of the significance of thermal energy is also critical since in tropical areas cultured algae are frequently raised at temperatures close to their lethal limits, and in cold climates temperature can be regulated to maximize yields.

(*iv*) Monitor crop and culture conditions and control the use of energy and materials to achieve optimum benefit/cost ratio. One of the greatest benefits of aquaculture is the ability of the farmer to influence the quality and supply of his crop to the market, but increasing levels of control are achieved at a cost in labour and capital. In capital-intensive cultivation, the regulation of costs and benefits can become particularly complex since large, intensively stocked, partly automated systems may be controlled by a few people. Close monitoring of culture conditions by automatic means and by the attention of skilled aquaculturists becomes essential and a knowledge of how to respond to changes in culture conditions is critical to successful crop production. Water temperature, light levels, water flow rates and population structure can all be regulated, but proper balances must be sought. For example, costs of supplying water must be balanced against fertilization costs.

(*v*) Harvest, process and market the yield; maximize efficiency or profitability by regulating aquaculture farm production to suit market structure. After algae have biosynthesized the desired end products, the aquaculturist must make an investment of capital and labour to harvest, process and market the yield. Harvest rates and harvest times are generally a compromise between the need to maintain optimal population densities and the need to supply the market with raw materials at the correct times. Some forms of algal cultivation, such as *Eucheuma* farming and developing forms of *Chondrus* farming, permit a relatively steady supply of raw material on a year-round basis but other crops, such as *Porphyra,* remain seasonal even under cultivation.

4 Future development

4.1 *Future development of industries utilizing algae*

Since 1950, the utilization of algae has steadily increased throughout the world and has developed as a truly worldwide undertaking. All present phases of the algae industry are expected to continue in this expansion. Steadily increasing worldwide needs for fertilizer and stock feed have stimulated the production of seaweed fertilizers and feed additives. The use of algae as human food is increasing as world population increases, and in the developed countries of North America and Europe human consumption of algal food products is increasing in conjunction with expansion of the health food trade. Although 1975 vegetable gum production receded from the record levels of early 1974, this industry is projecting steady growth. Attempts to synthesize inexpensive substitutes for vegetable gums have not been successful since these compounds are extremely complex and the reasons for differences in quality between gums are not well understood.

As the utilization of algae increases, cultivation can be expected to increase as well, especially intensive forms of culture which lend themselves well to vertical integration of raw material production with other aspects of the industry. Cultivation is also becoming increasingly necessary as more and more natural stocks are heavily exploited throughout the world, and demand for algal products exceeds supply.

Besides increasing the total supply, algal aquaculture is also attractive in that it has the capability of providing high quality raw material with specifically selected characteristics, production can be concentrated in geographical areas which are close to market or processing facilities, and algae have good polyculture potential since they are primary producers which do not compete with fish for nutrients. The production of algae may also be undertaken as part of sewage treatment. This is standard practice with freshwater effluents, and Ryther, with his co-workers, is studying the use of marine macrophytes for tertiary sewage treatment in Wood's Hole, Massachusetts, USA (Ryther *et al,* 1975).

4.2 *Constraints to development and technical problems*

The cultivation of algae has developed rapidly since 1950 and is continuing at an accelerating pace. As a result, many

technical problems have arisen, and solutions can only be provided through research and the accumulation of experience by aquaculturists. Virtually all areas of technical development would gain strength from international co-operation and communication between algae farmers. Some areas which require particular attention are the following:

(*i*) Pests and diseases are a matter of extreme concern in most intensive algal monoculture enterprises. Fungal, viral and bacterial diseases have been discovered in *Laminaria* and *Porphyra* culture, and it can be assumed that similar problems will arise in all forms of algal cultivation. Epiphytes also cause great concern, as do weeds in terrestrial plant culture, and means must be found for providing the desired crop with the maximal competitive advantage over other algae in a culture situation. Some forms of chemical control would also be useful, but such measures must be used with great care in order to protect environments adjacent to seaweed farms, and to ensure that only unwanted algae are selectively destroyed.

(*ii*) Seed stock selection will continue to be of major importance in seaweed cultivation. The principles of population genetics must be applied to plants with a sexual phase, and strain selection must be carried out with vegetatively propagating forms of algae. As fast-growing strains are developed, accommodation must be made for the possibility that they will be transported between areas of a country or sold internationally. Therefore, appropriate quarantine regulations must be promulgated and observed.

(*iii*) Applied algal physiology is essential to the further development of cultivation techniques. This was well demonstrated in the *Porphyra* industry, which was radically altered when Drew carried out reproductive physiological work leading to the technology for breeding *Porphyra* in hatcheries. Applied physiology becomes particularly important in the allocation of energy and materials in intensive cultures, where careful use of fertilizers profoundly affects production costs.

Finally, there are many aspects of seaweed life cycles and general physiology which are not understood even though significant effects have been observed in cultured algae. Doty and Alvarez (1975) have reported a 'senescence' phenomenon in which *Eucheuma* fronds show slow growth, and the author has observed a similar phenomenon in *Rhodymenia*. Propagation of macrophyte clones is also a recent innovation which will probably reveal many previously unknown algal physiological phenomena.

(*iv*) Methods for correlating and utilizing knowledge are as crucial as the need for producing information. Although international conferences and journals enable exchange of information, there are still barriers to the useful sharing of knowledge among cultivators of algae. Much information is regarded as being proprietary by aquaculturists for political or business reasons, even though some sharing of information and experiences would benefit everyone.

There is also an ever-present need for translation services so that valuable documents in English, French, German, Chinese, Japanese, Russian and other languages can be made available to practising aquaculturists. Available information must be correlated and integrated to produce useful economic management models, and the techniques of computer simulation are being usefully applied to algal cultivation. Simulation modelling by scientific and technical support workers can provide an invaluable service to the practising aquaculturists who, in the last analysis, are responsible for raising the crop.

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Seaweed Aquaculture in the Northwest Pacific

Y. Saito

Abstract

Seaweeds have long been utilized by man as foodstuffs, fertilizers, feeds and industrial materials. They are available as food for useful shellfishes, and the algal 'aquatic forest' provides spawning and nursery environments for many coastal marine animals.

Many varied techniques have been developed for seaweed cultivation. In some seaweeds, artificial seeding and seedling culture have been realized. If consumer demand for seaweeds increases, the production of cultivated seaweed will also be increased. In order for this to be accomplished, efforts should be made to: increase the harvest per unit of cultivating area; improve the quality of harvests; and reduce production cost.

Many efforts have been made to improve seaweed propagation. Effective measures with some seaweeds include: provision of new substrates, improving old substrates, weeding, transplantation of mother plants and cultured seedlings and spore sowing. Prevention of the effects of grazers has also been tried. In future the techniques may include changes in broader areas of the seaweed environment such as current and

wave action and light intensity.

The cultivation of 'Nori' (the red alga, *Porphyra*) and 'Wakame' (the brown alga, *Undaria*) in Japan are described in considerable detail. The status of cultivation of these seaweeds in China and the Republic of Korea is also noted.

Cultures des algues dans le Pacifique nord-ouest

Résumé

L'homme utilise depuis longtemps les algues comme aliment, engrais, fourrage et matière première industrielle. Les algues servent de nourriture à des mollusques utiles, et la 'forêt aquatique' quelles forment offre un terrain de frai et d'élevage à de nombreuses espèces marines côtières.

De multiples techniques ont été misse au point pour cultiver les algues. Pour certaines algues on a réalisé l'ensemencement artificiel et la culture de plants. Si la demande d'algues s'accroît, la production d'algues cultivées pourrait du même coup augmenter. Pour parvenir à ce résultat, les efforts devraient viser: à accroître la récolte par unité de superficie cultivée; à améliorer la qualité des récoltes; et enfin à réduire les coûts de production.

De nombreux efforts ont été entrepris pour améliorer la multiplication des algues. Parmi les mesures qui se sont révélées efficaces pour certaines algues figurent: la réalisation de nouveaux substrats; l'amélioration des anciens substrats; le désherbage; la transplantation de plantes mères ainsi que la culture de plants et l'ensemencement à l'aide de spores. On a également essayé de parer à l'action des brouteurs. Les techniques futures pourraient avoir recours à des changements sur des zones plus vastes du milieu, par exemple l'action du courant et des vagues et l'intensité lumineuse.

La culture au Japon de 'Nori' (algue rouge *Porphyra*), et de 'Wakame' (algue brune *Undaria*) est décrite d'une façon très détaillée. L'état de la culture de ces algues en Chine et en République de Corée est également mentionné.

Cultivo de algas en el noroeste del Pacífico

Extracto

Hace tiempo que el hombre utiliza las algas para la preparación de alimentos, fertilizantes, piensos y productos industriales. Las algas sirven de alimento a moluscos y crustáceos que son útiles para el hombre, y los 'bosques acuáticos' de algas ofrecen refugios para el desove y la cria a muchos animales marinos que viven en las zonas costeras.

Son muy variadas las técnicas que se utilizan para el cultivo de algas. En algunos casos se llega incluso a la siembra artificial y al cultivo desde semilla. Si aumenta la demanda de algas, aumentará también la producción de algas cultivadas. Para ello será necesario esforzarse por aumentar los rendimientos por unidad de zona de cultivo, mejorar la calidad de las cosechas y reducir los costos de producción.

Se han realizado muchos esfuerzos para mejorar la propagación de las algas. Entre las medidas utilizadas con eficacia para algunas algas figuran: preparación de nuevos sustratos, mejora de los antiguos sustratos, eliminación de malas hierbas, transplante de plantas reproductoras y de plantones cultivados, y siembra por esporas. Se ha intentado también impedir los efectos de los organismes que se alimentan de algas. Las técnicas futuras podrían incluir cambios más amplios del medio ambiente de las algas, modificando por ejemplo la acción de las corrientes y el oleaje y la intensidad de luz.

Se describe con mucho detalle el cultivo de 'Nori' (alga roja, *Porphyra*) y 'Wakame' (alga parda, *Undaria*) en el Japón y se dan también algunos datos sobre la situación del cultivo de estas algas en China y la República de Corea.

1 Introduction

The use of seaweeds by man has a long history. They have been utilized as: foodstuffs, animal fodders, fertilizers and industrial materials, such as agar-agar, pastes, alginates, potassium and iodine, and various medicines, as shown in Table I. Japanese and east Asians have particular preferences for seaweeds as food, and most of the seaweeds harvested are consumed as foodstuffs. In western countries, however, only little seaweed is eaten, and this because of its palatability or as a health measure. However, as the world's population increases, with consequent shortage of food supply, the amount of seaweed may have to be increased in the future for use as human food.

The sublittoral belts of coastal zones are inhabited by various abundant large-sized seaweeds, sometimes called an 'aquatic forest'. Such 'forests' are composed mainly of seaweeds belonging to the families Laminariaceae and Sargassaceae. The sandy mud bottoms of inland seas and bays support a thick growth of *Zostera*, a spermatophyte. The seaweeds of the aquatic forest are favourite foods for useful shellfishes, such as abalone (*Haliotis*) and top-shells (*Trochus*). The aquatic forest and '*Zostera* zone' are also spawning and nursery grounds for many marine animals. Much effort has been made, therefore, to keep and enlarge the area occupied by these useful plants.

2 Cultivation of seaweeds

The progress of seaweed cultivation depends upon consumer demand. At present, edible seaweeds are intensively cultivated in Japan, the Republic of Korea and China. The genera cultivated here are: *Porphyra, Monostroma, Enteromorpha, Undaria, Laminaria* and *Nemacystus*. The red alga *Eucheuma*, used to produce kappa carrageenan, is cultivated in the Philippines.

2.1 *Cultivation of 'Nori' (Porphyra)*

2.1.1 *Japan*

2.1.1.1 Development of Nori cultivation. In a broad sense, cultivated Nori (laver) includes not only the red alga *Porphyra* but two green algae, *Monostroma* and *Enteromorpha*. The latter are usually cultivated on different grounds from those of *Porphyra*. All of these harvested seaweeds are processed in rectangular paper-like sheets (about 20 × 20 cm in size and about 3–4 g in weight). The greatest amount of the production is that of *Porphyra*.

After the second world war, cultivation of Nori in Japan developed rapidly, especially so during the past ten years. At present, Nori is cultivated in most bays along the Pacific coast of Japan and inland sea areas. About 50 000 families are engaged in its cultivation on Nori grounds about 70 000 ha in area. They produce about 8–10 thousand million sheets of Nori, having a value of Yen 80–100 thousand million[1].

Major reasons for this development are: (*i*) A shortage caused by an increase in Nori consumption, due to population growth and changes in diet. (*ii*) Increase in net income of the cultivators. This increase due to a rise in market price made Nori cultivation one of the most profitable aquacultures and promoted its expansion throughout Japan. (*iii*) Expansion of Nori grounds. Increase in population and development of industries in the coastal zone made the coastal waters richer in nutrients, making it possible for Nori cultivation to be extended to areas other than those close to nutrient-rich river mouths.

Under this situation, strong demands were made for advances in cultivation techniques.

2.1.1.2 Techniques of Nori cultivation. The methods of Nori cultivation and recent changes in its production are shown in Figs 1 and 2.

(*a*) *Collectors or cultivating devices:* Originally, the structures on which the edible plants (the thalli) were grown, were tree twigs, split bamboo poles or bamboo branches. Today, nets made with synthetic twine (about 2–3 mm in diameter of three-twist yarn) are commonly used. These nets are rectangular, usually about 1·2 m wide and 18 m long, of about 30 cm stretched mesh. 'Blinds' or screens made of split bamboo connected with rope at intervals of about 10–15 cm are also used to some extent.

The nets or blinds are suspended from bamboo poles,

[1] US$ 1.00 = Yen 303.00

TABLE I
THE UTILIZATION OF SEAWEED IN THE WORLD

Class	Genus \ Use	Foodstuff	Material for agar-agar	Material for alginates	Material for paste	Feeding	Manure	Source of potassium chloride and iodine	Medical purposes	Continent where seaweed is used
Green Seaweed	*Monostroma* *	×								E, J
	Enteromorpha *	×				×				E, P, J.
	Ulva	×				×	×			E, NA, SA, P, J
	Codium	×							×	EA, J
Brown Seaweed	*Endarachne*	×								J
	Petalonia	×								J
	Nemacystus *	×								J
	Tinocladia	×								J
	Cladosiphon	×								J
	Heterochordaria *	×								J
	Laminaria *	×		×		×				E, EA, J
	Kjellmaniella							×		J
	Ecklonia *	×		×			×	×		J
	Eisenia *	×		×			×	.×		J
	Undaria *	×								EA, J
	Alaria	×		×		×	×			E, NA, J
	Nereocystis *	×		×			×	×		NA
	Macrocystis *			×			×	×		NA, P, SAF
	Pelagophycus			×				×		NA
	Durvillea	×								SA
	Fucus	×				×	×			E, NA
	Pelvetia					×				E, NA, J
	Ascophyllum					×				E
	Hizikia *	×								J
	Sargassum *	×					×	×		NA
Red Seaweed	*Porphyra* *	×								EA, E, NA, SA, J
	Nemalion	×								J
	Asparagopsis									P
	Gelidium *	×	×							EA, P, NA, SA, J
	Pterocladia	×	×							P, J
	Acanthopeltis		×							J
	Gloiopeltis *	×	×		×					EA, J
	Grateloupia	×	×		×					P, J
	Pachymeniopsis				×					J
	Gigartina	×	×		×					E, EA, J
	Furcellaria		×							E
	Chondrus	×			×					E, NA, EA, J
	Iridaea	×			×					E, J
	Carpopeltis	×			×					J
	Gracilaria *	×	×		×					E, EA, SAF, P, J
	Turnerella				×					J
	Meristotheca	×			×					J
	Eucheuma	×	×		×					P, EA, J
	Hypnea	×	×							P, J
	Ahnfeltia	×	×		×					EA, P, E, J
	Rhodymenia	×								E, NA
	Gymnogongrus	×								P
	Ceramium		×		×					J
	Campylaeoephora		×		×					J
	Digenea								×	J
	Laurencia	×								E, EA

E: Europe, NA: North America, SA: South America, SAF: South Africa, P: Polynesia, EA: East Asia, J: Japan.
* Important genera which are cultivated or propagated.

driven into the bottom of the shallow sea so that the flat surface is parallel to the water surface. These man-made structures have many advantages over the old ones: they require less care, are resistant and produce more.

By using these nets, Nori cultivation has been extended to new areas with deeper water. Nori cultivation grounds are also developed by using a floating system. In this system, synthetic ropes are supported on the surface of the sea by buoys and held by anchors. Twenty nets with small buoys are usually stretched between the ropes. This system makes it possible to utilize even offshore waters of about 20 m depth with strong wave action.

(*b*) *Culturing of conchocelis:* The cultivation of *Porphyra* is now completely dependent on the use of spores from its cultured 'conchocelis stage'. This filamentous stage of *Porphyra* was originally described as a separate shell-boring algal species under the name of *Conchocelis*, but is now recognized as the sporophyte stage. This stage develops in mollusc shells, from carpospores produced sexually by the main plant or thallus (the gametophytic generation). In turn, the conchocelis produces non-motile floating monospores ('conchospores') which develop into the thallus—the part of the alga which is eaten.

Culture of the conchocelis is started in March or April, generally using oyster or scallop shells as substrates. Recently, transparent vinyl films covered with calcite granules

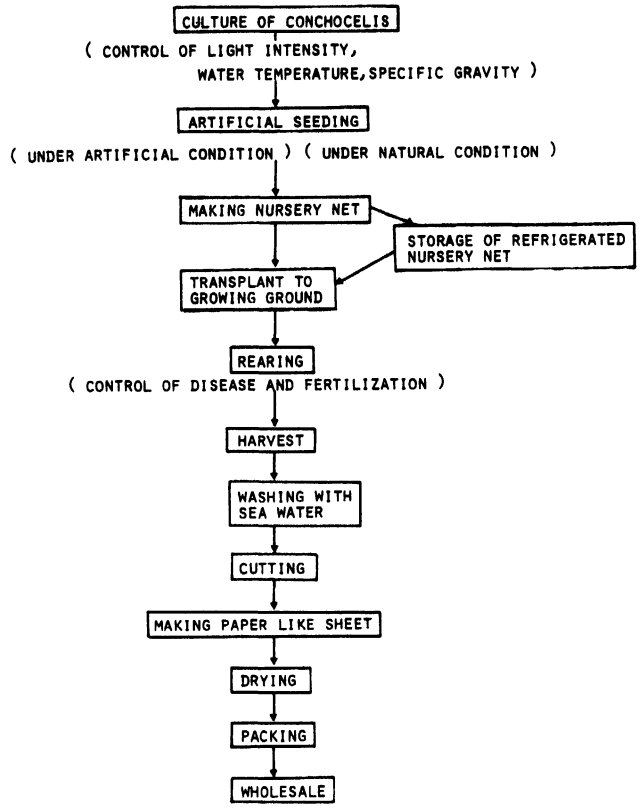


Fig 1. Process flow diagram of Nori (*Porphyra*) cultivation

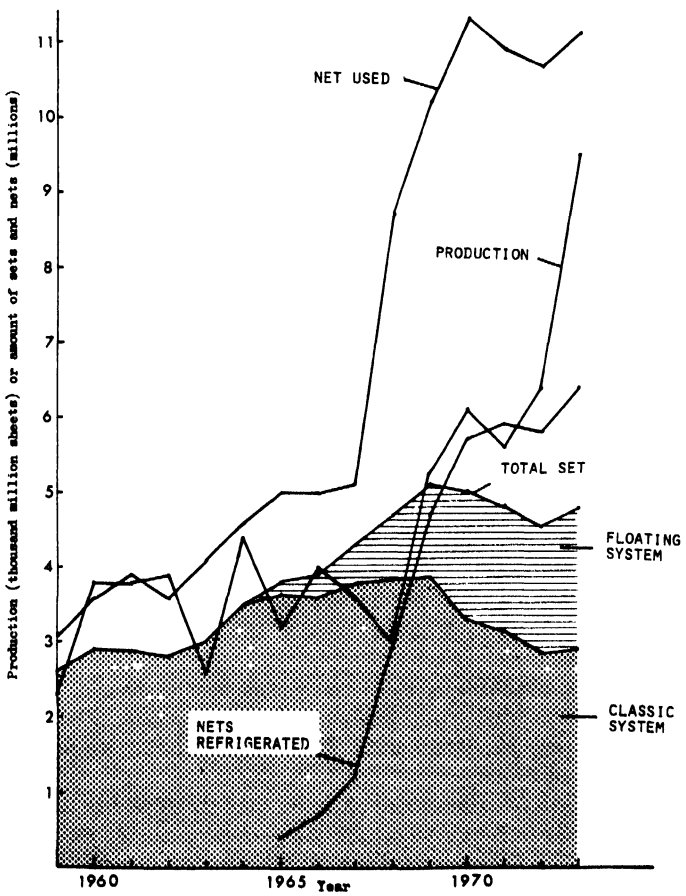


Fig 2. Changes in Nori production of *Monostroma* and *Enteromorpha* and in the number of cultivating sets and nets used for their production, and number of nets stored in refrigerators for *Porphyra* only

of 1–2 mm diameter have been partly used as a substitute for shells. These substrates are placed on the bottom of a shallow tank filled with seawater to await 'seeding' with carpospores from the parent thalli.

Carpospores are obtained as follows. A suspension may be obtained by drying parent thalli overnight and immersing them in sea water for 4–5 hours the next morning to induce carpospore formation. Or, thalli may be pulverized in sea water which is filtered to obtain a carpospore suspension. (Pieces of cut thalli may also be placed in the tank containing the substrates to induce natural release of carpospores.)

Howsoever derived, the carpospores are introduced into the tank where they attach to the substrate. Once attached, they burrow down into it (into the pearl layer when shells are used) to develop into the conchocelis stage.

The substrates with conchocelis are collected and suspended in tanks of 0·5–1·0 m in depth, where they are kept throughout the summer. Water temperature, the quality of the sea water and the illumination in the tank are all controlled artificially, so that conchocelis grow well and without disease. At the end of summer, the conchocelis matures and produces many conchospores.

A so-called 'free-living conchocelis' is also cultured without substrate. Clean matured thalli are put into a sterilized vessel with enriched sea water, and taken out after release of their carpospores. The carpospores grow into globular colonies of conchocelis (3–4 mm diameter) on the bottom of the vessel within two months. Some of these colonies are put into other vessels and cultured in water agitated by shaking the vessel or by bubbling sterilized air through it. As the colonies grow larger, they are divided into smaller ones, and through repetition of division and culture a large quantity of free-living conchocelis are produced. These free-living immature conchocelis are cultured for a long time under controlled conditions of high temperatures ranging from 24° to 28°C and illumination at 750 lux at 8 hours per day. Conchospores are produced by the maturing conchocelis, the liberation of which is accelerated by low temperatures of 17°–18°C and high illumination rate of 1000–4000 lux. They are released by cutting the conchocelis into small pieces to facilitate seeding of the shell substrates provided for this purpose.

(*c*) *Seeding:* In autumn, when the water temperature goes below 23–24°C, conchospores start being released and artificial seeding begins. Some pretreatment is applied in advance of this seeding procedure: lowered temperature, modified illumination and addition of chemical substances.

Artificial seeding of conchospores is divided into two: (*i*) artificial outdoor seeding, and (*ii*) artificial indoor seeding.

(*i*) In artificial outdoor seeding, 20–40 nets are layered together and set out in the sea. Shells or pieces of film with mature conchocelis are put into vinyl bags, which are hung under the nets in order to collect conchospores on the net twines. Sometimes the layered nets are placed in a large sealed vinyl bag containing conchocelis-bearing shells and sea water. The bag is left floating on the surface of the sea. After several days, the spores have fixed themselves to the nets and the nets are removed from the bag. This method prevents waste of spores and can be practised even in deep waters.

(*ii*) Artificial indoor seeding is further divided into two methods. In one, a layer of net is rotated over a wheel or as a belt in a tank of water above the conchocelis lying on the

bottom. Conchospore attachment to the nets is induced by this movement which stirs up the spore-containing sea water. In another method, the nets lie on the water surface and the tank water is stirred by compressed air bubbles forced through lateral pores of pipes lying on the bottom. Again, the contact with and attachment to the net fibres is facilitated by keeping the water in motion.

There are several advantages in artificial seeding. In outdoor seeding, attachment of spores to the nets is ensured. With indoor seeding, regulation of spore density on the net twines is possible, and the operation is not affected by the weather.

(*d*) *Preparation of young buds:* Layered nets, 20–40 in number, which are set for seeding, are separated into sets each of 5–6 layered nets and attached to new supporting poles or rafts. The germlings are exposed naturally to the air at ebb tide under the pole system and artificially by elevation of the nets in the floating system. The cultivators control the period of exposure according to climatic and sea conditions, so that the buds do not suffer from severe drying out and the growth of harmful weeds and diatoms.

When the buds are 5–30 mm in length, some of the nursery nets are removed from the cultivating ground. These nets are dried until the moisture of the young buds is diminished to about 20–30%. The nets are then packed in polyethylene bags and put into cold storage at −20°C. Here buds can be kept alive for more than six months. The refrigerated nets can be used to increase production as a later crop or as a back-up or security measure when the planted *Porphyra* suffers from severe disease. In the past, when too many nets were set up during bud rearing, these buds suffered damage, resulting in a reduction of harvest. This problem has now been solved by reducing the nursery nets in each cultivating ground to a manageable number.

(*e*) *Growth and harvest:* In about 50 days after germination, the plants have grown to 15–20 cm in length and are ready for the first harvest. After the first harvest, other buds on the net will grow to be harvested in another 15–20 days. The harvest from a net can be repeated several times during the same season. When a crop on a net decreases after repeated harvests, the net is replaced with a new net which has been kept under refrigeration and can produce a crop in 15–30 days. The amount of *Porphyra* thalli harvested each time is generally equivalent to 500–2 000 sheets of dried Nori per net.

At times, disease occurs in association with unsuitable weather, environmental conditions in the sea and with overpopulation of the plants on the cultivating ground. The trouble is prevented fairly well by controlling the number of nets to be set out.

In some cases, where the nutrients are poor, or when a shortage of nutrients occurs, the cultivating grounds are fertilized to get a better quality of harvest.

Today, the plants are harvested rapidly by machines which are adapted for each rearing system. By using these machines, labour at sea is reduced and disease prevented.

(*f*) *Processing techniques:* Harvested *Porphyra* thalli are processed into dried products having rectangular shapes by the cultivators themselves. All of the operations are now mechanized. The harvested *Porphyra* thalli are washed thoroughly with sea water to remove contamination, such as diatoms and mud, chopped into small pieces and placed in fresh water. The thalli are then spread on screens of fine meshed bamboo or plastic, and dried. The drying has to be carried out quickly at a moderate temperature, commonly lower than 50°C, and drying is completed in 2–3 hours. Under these conditions, the thalli are kept alive until the end of the procedure so that their good qualities, such as glossiness, sweet odour and good taste are enhanced.

When the quantity of the plants harvested exceeds the manufacturing capacity, the plants can be stored temporarily at about −20°C after about 50% reduction of their moisture by centrifuging.

(*g*) *Reclamation of Nori grounds:* The following conditions are required for a suitable Nori ground: (*i*) sufficient exchange of sea water by currents and waves, (*ii*) good nutrient supply, and (*iii*) moderate inflow of fresh water.

About ten years ago, civil engineering principles were introduced into Nori cultivation. Waterways have been dug to improve the exchange of water and distribution of fresh water.

(*h*) *Breeding of Porphyra and introduction of exotic species:* Today the most common species of cultivated *Porphyra* are *P. tenera* and *P. yezoensis*.

Selection and transplantation of specific populations of *Porphyra* can be accomplished easily through conchocelis culture and artificial seeding. Cultivators have recently selected some useful lines from populations of *P. tenera* and *P. yezoensis* which have characteristics of high growth and disease resistance. Exotic species of *Porphyra* which have excellent characteristics were also introduced from Argentina, Canada and the Federal Republic of Germany.

(*i*) *Indoor artificial culture:* Indoor artificial culture techniques were recently established by an industrial chemical company. In this method, the conchocelis are cultured free without substrates and the fronds are also floated. A free-living culture is very suitable for *Porphyra* production because it is much easier to prevent its contamination by bacteria, yeast, fungi and unwanted algal cells. The frond culture medium and apparatus are unique.

The method has not been industrialized, however, as the production cost is too high and a recent increase of the harvest indicates oversupply from cultivating grounds.

2.1.1.3 Problems of Nori cultivation. The Nori harvest attained a total of about 10 thousand million sheets in 1973. This created an oversupply of the products, especially those of low quality, which led to low market prices and a decrease in the net income of Nori cultivators. Moreover, mechanization of cultivation has raised production costs, especially those of small-scale operations. The most serious problem in Nori cultivation is its administration. In order to stabilize its economics, the cultivators have to make every effort to increase the harvest per cultivating unit, produce a high quality of product and reduce the costs of production.

In the near future, Nori cultivators will be divided into two groups: one group going over to mass production, the other going into small-scale operation to produce a special quality of Nori.

Under these situational changes, one can expect that: (*i*) Decreases in harvest—which are generally caused by disease—will be prevented by techniques to forecast and prevent disease occurrence. (*ii*) Each cultivation process will be simplified and improved in order to reduce production costs. (*iii*) Product quality will be improved through development of efficient fertilizing techniques and disease

prevention. (*iv*) Breeding of new lines and the use of exotic species, especially those with rapid growth and more resistance to diseases, will increase.

2.1.2 *Republic of Korea. Porphyra* plants have been cultivated for many years in most of the coastal waters in southern Korea except in some waters of the eastern coast. In the thirties the cultivation was developed rapidly by introducing a new technique, in which split bamboo screens were used. Ten years prior to the second world war, Korean Nori products amounted to about one thousand million sheets, most of which were exported to Japan.

After the second world war, production decreased for a time and then increased again. In 1970, it was reported that Korean production reached two thousand million sheets. Recently, however, the amount of Nori exported to Japan has been reduced.

Under these circumstances, cultivation techniques did not advance much after the second world war. Most of the cultivation devices consist of split bamboo screens and bundles of bush, and only a few nets are used. Modern techniques, such as artificial seeding, cold storage of nursery nets and the floating net system are not much used. If the domestic consumption and export of Nori were to be increased, Nori cultivation would have the possibility of improving its techniques and increasing its harvest because there are many waters suitable for Nori culture and an abundant labour force in the Republic.

2.1.3 *China.* In China, Nori cultivation began after the second world war and has since developed gradually in many localities. The techniques of cultivation and manufacture of Nori have lagged behind those of Japan, and nets and bamboo branches are still used as cultivation devices. It is reported that steps are now being made to improve the techniques, *eg,* frozen storage of *Porphyra* thalli.

If consumption of Nori were to increase, its cultivation in China would proceed more rapidly because there are many waters on the coast of China suitable for its cultivation.

2.2 *Cultivation of 'Wakame' (Undaria)*

2.2.1 *Japan*

2.2.1.1 Development of *Undaria* cultivation. Three species of the brown alga, *Undaria*, are harvested: *U. undarioides, U. pinnatifida* and *U. peterseniana.* In Japanese, 'Wakame' indicates the species *U. pinnatifida* but it is often used as a general term for the genus *Undaria.*

Of these species, *U. pinnatifida* has been the one most familiar to people as food and the one mostly harvested. Because of sufficient supply of the product from natural beds, its cultivation did not develop until shortages in the natural product occurred in the sixties. At that time, consumption of *Undaria* increased with an increment of population and development of a new salted product preferred by consumers because of convenience in its use. This increase of consumption stimulated the development of *Undaria* cultivation which was encouraged by the Japanese Government in order to increase the income of fishermen. Its cultivation was promoted, especially along the north Pacific coast of Japan, with the support of the Government by setting up cultivation equipment offshore and nurseries for *Undaria* seedlings.

Cultivation advanced mainly in the bays of northern districts and developed gradually in other areas throughout the country. Cultivation was also developed remarkably by expansion of the cultivation grounds in offshore waters. At present, *U. undarioides* and *U. peterseniana* are also cultivated to some extent in the southern districts.

Recent changes in *Undaria* production are shown in Fig. 3, where production from cultivation and natural beds is described separately. The total production is now more than twice that produced before cultivation started. Production from cultivation is over 100 000 tons, exceeding the harvest from natural beds.

2.2.1.2 Techniques of cultivation. The life history of *Undaria*, in simplified form, consists of an alternation of generation between: (*i*) an asexual form (the sporophyte) which constitutes the principal or macroscopic algal body, and (*ii*) the sexual gametophyte which is microscopic in size. The sporophyte produces motile diploid zoospores from its sporophyll area. These settle on a substrate, where they germinate to produce the gametophyte. From the union of the latter's sexual products (sperm and egg) a zygote is produced which develops into the sporophyte. It is this sporophyte—the thallus and fronds—which is eaten. Fig. 4 is a process flow diagram of *Undaria* cultivation.

(*a*) *Spore collection and germling culture:* Preparation for seedling culture begins at the end of the season when *Undaria* plants mature and develop zoospores (in May–June in northern waters, in April–May in southern waters). 'Seedling twines' are now usually used for spore collection and the culture of germlings. The material used for seedling twine is mostly synthetic fibre-spun yarn, 2–3 mm in diameter. The 100 m long twine is wound around a square

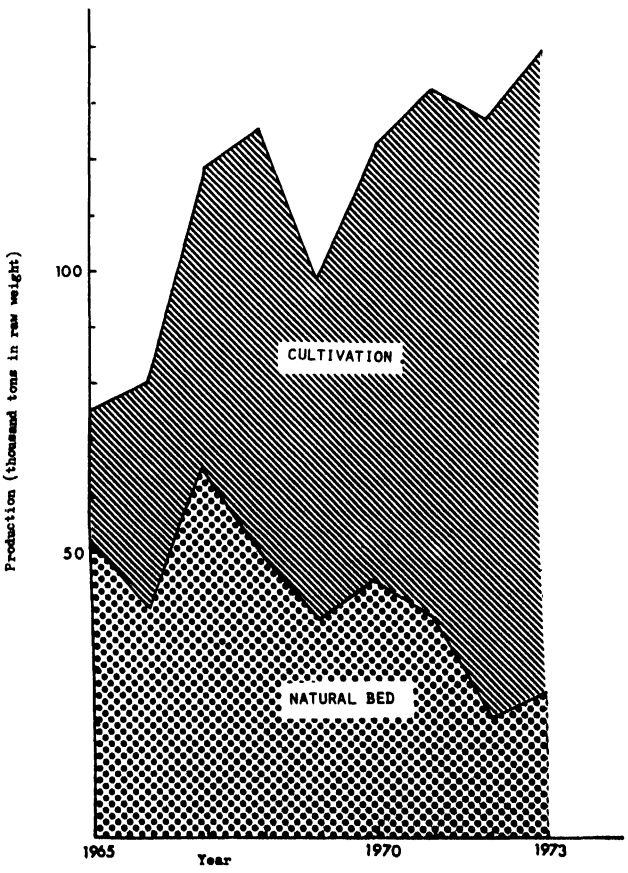


Fig 3. Annual changes in *Undaria* production from the cultivation of natural beds

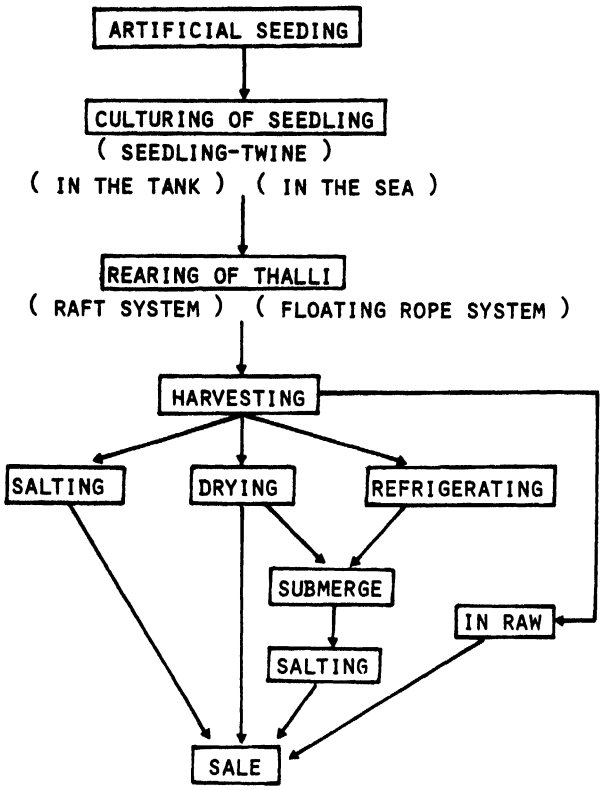


Fig 4. Process flow diagram of *Undaria* cultivation

plastic frame, 50 × 50 cm, at intervals of about 1 cm.

Mature sporophylls of *Undaria* which have been partially dried, are placed in a tank filled with fresh sea water. After a large number of spores have been released into the sea water, the sporophylls are removed. The 'string' or twine frames are then arranged in layers inside the tank to collect the zoospores. After one to two hours the frames are removed and hung vertically in culture tanks about 1 m in depth. The so-called seedlings which develop are cultured throughout the summer. Within the tanks, according to changes of water temperature, light intensity is regulated so as to keep the growth of the gametophytes in good condition and their survival rate at high level. If necessary, the tank water is changed, circulated or supplied with nutrients.

Germlings of *Undaria* develop in the autumn when the water temperature drops below 20°C. The frames with their seedling twines are taken from the tanks and suspended in the sea from a raft in order to raise the germlings into healthy young thalli until they grow 2–3 cm in length.

In northern waters, where the period of seedling culture is short and invasions of fouling seaweeds and animals less severe, tank culture is not always used and the seedlings are cultured directly in the sea by hanging the frames from a raft. The depth of the frame is regulated according to seasonal changes of water temperature and the degree of insolation.

In recent years, however, the culture of *Undaria* seedlings has been carried out mainly in tanks and a large number of public and private nurseries of *Undaria* have been set up all over Japan. The annual production of seedlings in terms of the total length of seedling twines is estimated to be 60 million m.

(*b*) *Growing* Undaria *thalli:* Operations for growing *Undaria* thalli start in autumn (September–November) when the water temperature falls below 20°C and danger of attachment by epiphytic organisms diminishes. Seedling twines are attached to a rope (10–20 mm in diameter, of synthetic fibres) at suitable intervals. Sometimes the twine is cut into short pieces, 5–6 cm in length, and inserted in twists of the rope. The cultivation ropes are set in the sea with some kinds of cultivation equipment. In rough waters, the 100 m long cultivation rope is held in the sea with buoys and anchors, and often many branches of cultivation rope are hung from the main rope. In calm waters such as those in a bay, the cultivation ropes are stretched out horizontally in the sea by rafts.

The water depth for setting the cultivation ropes is 0–3 m in the northern low temperature districts, and 1–5 m in the southern high temperature districts.

The cultivation of *Undaria* was at first carried out in calm bays with simple rafts, but it has gradually progressed to the open sea using the floating rope system, and is now even carried on in waters of about 50 m depth with strong wave action.

Good growth of young thalli is expected at water temperatures of 15–17°C, but it is delayed at lower temperatures. The large pinnate thalli elongate well at temperatures below 12–13°C. However, the growth of plants may be depressed at temperatures below 5°C. Rapid currents and strong wave action are suitable for growth of the plants, but may damage the cultivation devices.

(*c*) *Harvest and manufacturing:* When the thalli have grown to more than 50–60 cm in length, the cultivation rope is hauled up to a boat and the thalli cut off with a sickle. When the density of *Undaria* plants is high at a locality favoured with a long period of optimal temperature for thalli growth, a number of thallus groups are produced, which differ from each other in growth. In such cases, the groups of well developed thalli are harvested first. This thinning process promotes more rapid growth in the remaining groups of underdeveloped thalli. In this way, harvesting from a rope can be repeated several times. When the density is low, the thalli are harvested by first cutting off their upper portions leaving the remaining portions to grow up again. In a locality with a short period of optimal temperature for thallus growth, it is recommended that all the thalli be harvested at once when most of them have their maximum growth. The selection of methods depends on the economic value of the crops. The harvest from 1 m of cultivation rope in a season is about 10 kg in wet weight in the northern waters and about 5 kg in the southern waters.

Most of the products are dried in the sun or in a dryer, and sold as dried *Undaria.* Some of them are sold salted and some raw according to local demands. Some thalli are stored under refrigeration. The refrigerated *Undaria* and some of the dried product are submerged in water again and salted for sale.

(*d*) *Transplantation:* In *Undaria,* even the same species may have a differing thallus growth and product quality, depending upon the habitat. However, the characteristics of a population such as the growth rate and thallus shape are maintained to some extent through two or three generations after it has been cultivated at a place remote from its native locality. Transplantation of those *Undaria* characterized by superior qualities may therefore be carried out.

2.2.1.3 Problems of *Undaria* cultivation. In the last few years, there has been an oversupply of *Undaria,* especially products of low quality. Consequently, the price of the

product and the net income of *Undaria* cultivators has fallen. Cultivators will have to make an effort to increase their income through the production of a high quality product and reduction of the production cost.

However, the nutrient requirement of *Undaria* is comparatively low, and its cultivation devices, especially the floating rope system, are resistant to strong wave action. Consequently, profitable cultivation can be expected in the open sea.

Under these circumstances, one can expect that: (*i*) The harvest per cultivation unit will be increased and production costs reduced through the development of culture techniques to produce more healthy seedlings, as well as development of techniques to prevent ingestion of young buds by grazers, such as isopods, snails and fish. (*ii*) Development of efficient fertilizing techniques will improve product quality.

2.2.2 *Republic of Korea.* In about 1960, the use of seedling twines was started in the Republic of Korea and the cultivation of *Undaria* began with the introduction of techniques from Japan. This cultivation developed gradually in many localities on the south coast.

Recently, public and private nurseries of *Undaria* seedlings have been established in many places. The annual production of seedling twines is estimated to be about 14 million m. The total amount of harvested *Undaria* is about 30–40 000 tons, of which the production through cultivation attains 6–7 000 tons in raw weight.

Undaria has recently been in oversupply, as the amount of domestic consumption and of export to Japan did not increase as expected. If consumer demand for *Undaria* increases it will, however, be possible to increase its cultivation.

2.2.3 *China.* After the second world war, both *Undaria* and *Laminaria* cultivation were industrialized in China. Thirty thousand tons of raw product was produced—mostly *Laminaria*. The production from *Undaria* cultivation appears to be increasing and will so continue in future.

3 Improvements in seaweed propagation

Many efforts have been made in Japan to increase the natural production of useful seaweeds such as *Laminaria, Undaria* and *Gelidium*. These improvements in propagation have been carried out mainly with the support of the Government, but local self-governing bodies and fishermen's co-operative associations have also made individual efforts to increase natural production.

In Korea, work has also been done to increase the natural harvest of *Undaria*.

Recently, attempts at aquatic 'afforestation' to improve spawning and nursery grounds for coastal marine life and to provide more seaweed as feed for useful shellfishes, or as a conservation measure, have been carried out in Japan and the USA.

Sometimes large seaweeds almost disappear over extensive areas and calcareous algae overgrow rocky bottoms. This phenomenon, which is called 'Isoyake' (decadent sea shore) in Japanese, lasts for several years. It causes a reduction in the production of useful seaweed and abalone (*Haliotis*) and also affects the production of marine fishes. Many studies have been made to determine the causes of the Isoyake. It has been found recently that feeding on young buds by grazers is one of the reasons for the phenomenon. When a seaweed population has been reduced through some accident, abalones, turbos (*Turbo*), sea urchins (echinoids) and other grazers may consume the remaining seaweeds and ingest the young seaweed buds which are necessary for recruitment. Consequently, seaweed population recovery is very slow and transplantation of cultured seedlings coupled with prevention of invasion by grazers may be useful for recruitment (see 3.1 below).

3.1 *Improvements in techniques*

The techniques used are both biological and engineering, used separately or together.

(*a*) *Provision of artificial substrates:* It has proved effective to set stones or concrete blocks into or around the seaweed ground to enlarge the seaweed beds and increase natural algal crops such as *Laminaria* and *Gelidium*. The yield in the areas where new substrates are set is nearly the same as that in the adjacent natural beds. This method can not be effectively applied to: areas of low productivity, Isoyake areas, and areas where the new substrates are moved away by wave action or become embedded.

These improvments are often combined with setting out mother plants or seedlings of *Undaria, Eisenia, Ecklonia* and *Sargassum* in areas where native plants do not exist.

(*b*) *Blasting rocky reefs or rock surfaces:* Rocky reefs are blasted with dynamite to modify the depth of rock and to expose new rock surfaces for seaweed propagation. The blasting also results in the expansion of surface area by scattering the rock blocks, and is useful in eliminating injurious weeds. The method is adapted successfully in the propagation of *Undaria* and *Laminaria*.

(*c*) *Weeding:* Perennial marine weeds, such as *Phyllospadix* and *Sargassum*, are likely to cover the beds of useful seaweeds such as *Laminaria, Undaria* and *Gelidium*, resulting in their reduced production. These harmful weeds are eliminated with tools by diving or from a boat. This operation is found to be effective in increasing the *Undaria* crop for a season and the *Laminaria* and *Gelidium* crops for one or two years.

(*d*) *Control of harvesting methods and period:* Harvesting methods and periods are controlled to prevent a decrease in released spores due to unlimited harvesting of immature plants. In *Undaria* and *Gelidium*, maximum production is usually attained by enforcement of prohibited harvest periods. In Japan, the methods and periods of harvesting are controlled by the fishermen's co-operative association which is given the privilege of seaweed harvest.

(*e*) *Transplantation of mother plants:* Mother plants held in the twists of a rope or tied with rope are held down by sinkers on natural beds or artificial substrates, aiming at ensuring spore attachment and an increase in population density. With some littoral algae, the mother plants are fixed on the rock surface with cement. This work does not appear to be very effective except with *Hizikia* and *Sargassum*.

(*f*) *Sowing:* A suspension of spores is prepared by inducing spore release from plants which have been partially dried and then immersed in sea water. Sometimes, in the case of *Hizikia*, embryos are collected by shaking the mother plants in sea water. The suspension of spores or embryos is poured onto a resurfaced rock by wading out to it during ebb tide. Sea water is sprinkled on the fixed spores

or embryos to protect them from drying until the rock surface is submerged. This operation is quite effective with littoral algae, such as *Hizikia* and *Gloiopeltis*, in increasing their production.

(*g*) *Transplantation of cultured seedlings:* Spores or embryos are collected on twines or nets in a tank and are cultured. When buds appear, the seedling twines, which are wound on concrete blocks, and nursery nets to which sinkers are attached, are set down on rocky reefs or newly established substrates. This method is applied to *Undaria, Eisenia, Ecklonia, Sargassum* and others. The plants which develop on the twines and nets form the basis of new aquatic forests.

In the US, seedlings of the giant kelp, *Macrocystis*, have been cultured on plastic rings and the rings set on rocky substrates using an underwater epoxy cement. Methods for the mass culture of *Macrocystis* embryos and their dispersal into the sea have been developed in the US recently. *Macrocystis* seedlings attached to polyethylene film substates or glass fibre cloth substrates are cultured in a refrigerated room in a long tray through which chilled, filtered and sterilized sea water flows. The embryos growing on the substrates are scraped off, suspended in sea water and dispersed on a rocky sea bottom by pouring them down through a hose. Sometimes, dispersal is aided by a diver who scrapes tiny plants off the substrate near the rocky bottom. These methods seem to be effective in the restoration of kelp resources.

Transplanted buds are often eaten by gastropods and other grazers, resulting in failure in their propagation. Two methods have been tried to prevent this damage to the buds. One method is to try to supply these grazers with additional food by cultivating a large amount of seaweed at or near the surface of the sea as a substitute for the food otherwise provided by young planted buds. These trials have been carried out on a large scale in northern districts of the Pacific coast of Japan. In the other method, after the concrete blocks wound with seedling twines bearing young buds are set out, they are covered by cages of synthetic fibre twines and the harmful grazers in the cage are removed. The cage is in the shape of a box ($1{\cdot}5 \times 3 \times 3$ m) or a cylinder (3–10 m in diameter and 3 m high). The cage remains as protection from grazers until the plants become adult. This method has been tried in the southern districts of Japan and similar trials have been made in California.

3.2 *Problems of seaweed propagation*

The advancement of methods to improve propagation in natural beds depends on the economic situation. For example, the expenditure for setting out substrates is recovered within 4–5 years in *Gelidium* propagation and within 5–8 years in *Laminaria*; but the use of such methods for *Chondrus* or *Gloiopeltis* is not profitable, because the period of cost-recovery may be as long as 20 years.

However, since seaweed resources are useful both for harvest and as aquatic forests, their propagation should be continued and improved even without direct profit within a short period of time. As the growth of cultured plants is greatly influenced by natural environmental conditions, care must be taken to ensure selection of the right places and right times for artificial propagation. In the future, the techniques which can alter conditions, such as current, wave action and light intensity may have to be developed in order to improve seaweed propagation.

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The Industrial Development of Farmed Marine Algae: The Case-History of *Eucheuma* in the Philippines and USA

L. E. Deveau and J. R. Castle

Abstract

The red alga, *Eucheuma cottonii*, is a seaweed that produces kappa carrageenan, a food stabilizer with various applications. Its ability to be cloned and to grow vegetatively has made its large-scale farming possible in the southern Philippines where it is currently produced in large quantities, particularly by family farmers who have been assisted in their endeavours by Marine Colloids, Inc., through provision of materials and instruction in *Eucheuma* farming techniques.

Assuming a family farm in the southern Philippines of 0·5 ha of reef, using nylon monofilament lines supporting 7 500 plants, each of an initial weight of 200 g and growing to 3 kg in 90 days—a total harvest can be secured of 22 500 kg wet weight, from which a dry saleable weight of 2 250 kg is recovered. At PPs 1·30/kg, the revenue is PPs 2 925. Expenses (nylon line, plastic 'tie-ties', unmotorized boat and poles) total PPs 700, thus providing a net income for the first quarter only (when expenses are higher) of PPs 2 225. The net annual income to a family would be about PPs 10 250 or US$ 1 360. (Present family income in the Philippines is about US$ 400.) Larger size farms seem to have the potential to compete advantageously with other crops including sugar and coconuts.

A farm site for *Eucheuma cottonii* must be in a coral reef protected from storms, and shallow enough to facilitate driving poles but deep enough to be covered at low tide. There must be good water flow and an annual water temperature within 26°–32°C. White, sandy bottoms and areas with herbivores must be avoided. Farms should not be in a typhoon belt or areas of much seasonality. Test units should be established to determine site suitability with certainty.

Two systems of farming have been developed: (*i*) Net farming uses a $2{\cdot}5 \times 5$ m net attached to 4 poles and strung parallel to the bottom. The net lines of polyethylene have 127 intersections to each of which a 100 g piece of *Eucheuma* is attached with a thin plastic strip ('tie-tie'). Once the plants reach 1 200–1 500 g they are pruned to 500 g and the process continues. Prunings are dried at a 10:1 ratio and sold dry. (*ii*) Monoline farming, developed by farmers, has reduced maintenance in that the plants keep cleaner and is the principal method now used. However, the density of plants per m^2 is lower than in net farming and might be less advantageous if planting areas were at a premium.

During the 1970–74 period, farmed *Eucheuma* has increased from a negligible quantity (0·6 tons in 1971) to an estimated 10 000 tons in 1974, while wild *Eucheuma* has declined from 534 to 75 tons. In 1974 there were 2 249 families farming it in the Tawi-Tawi and Sulu areas. Export values rose during 1970–74 from US$ 168 210 to US$ 4 533 750. In 1973 the gross value of *E. cottonii* was US$ 20 378/ha compared with US$ 2 576/ha for sugar. The industry is stabilizing. It is

estimated that the annual production level for the Philippines is about 3 500 dry tons with an annual growth of 10%—representing the total world demand for *E. cottonii*.

Early technological, political and economic difficulties in establishing seaweed farms in the Philippines have been largely overcome. The major research on *E. cottonii* has been undertaken by the University of Hawaii and Marine Colloids, Inc. More research is required on faster-growing strains with higher carregeenan yields and on disease. Marine Colloids is now attempting to grow *E. spinosum*, used for iota carrageenan, vegetatively in the Philippines but has not yet found a suitable clone. The total demand would probably not exceed 4 000 tons annually.

Marine Colloids, looking for an alternative method of developing a supply of carrageenan, has been experimenting with *E. isoforme* in the Florida Keys, USA, since the summer of 1974 using a capital-intensive tank system. A tank of water is agitated by air to keep the alga in suspension to receive adequate sunlight and nutrients. Temperatures, light and fertilization are controlled. Comparisons between tank-reared and field plants are in progress. The present programme has two steps: (*i*) location of strains which remain viable throughout the year so that seed stock can be maintained through the winter, and (*ii*) to regenerate the seed each spring from winter-germinated spores.

La culture des algues marines à l'échelle industrielle: le cas de l'algue *Eucheuma* aux Philippines et aux Etats-Unis

Résumé

Eucheuma cottonii est une algue rouge qui produit les carragénates kappa, agents de stabilisation dont les applications sont multiples. Leur mode de reproduction par clone et leur croissance végétative permet l'exploitation de ces algues à une échelle industrielle aux Philippines méridionales, où elles sont produites en grandes quantités, notamment par de petites exploitations familiales aidées par la société Marine Colloids Inc., qui leur fournit du matériel et des instructions sur les techniques de culture d'*Eucheuma*.

Si l'on prend pour base une entreprise familiale des Philippines méridionales exploitant 0,5 ha de récif au moyen de lignes de nylon en monofilament auxquelles sont suspendues 7 500 plantes— chacune d'un poids initial de 200 g atteignant 3 kilos en 90 jours—elle peut ainsi récolter au total 22 500 kg de poids humide, sur lequel on récupère 2 250 kg de produit sec commercialisable. Au prix de 1,30 peso/kg, les recettes sont de 2 925 pesos. Les dépenses (ligne en nylon, bandes en plastique, bateau non motorisé et perches) s'élèvent au total à 700 pesos, ce qui laisse un revenu net pour le premier trimestre seulement (période pendant laquelle ces dépenses sont les plus grosses) de 2 225 pesos. Le revenu net annuel d'une famille se situerait aux environs de 10 250 pesos, soit US$ 1 360 (à l'heure actuelle, le revenu d'une famille philippine est de quelque US$ 400). Il semble que de plus grandes exploitations pourraient concurrencer avantageusement les autres cultures, y compris la canne à sucre et le cocotier.

La culture d'*Eucheuma cottonii* doit se faire dans un récif corallien protégé des tempêtes, assez peu profond pour que l'on puisse y enfoncer des perches, tout en l'étant assez pour être recouvert par l'eau à marée basse. Le flux de l'eau doit être suffisant et sa température annuelle doit se situer entre 26°C et 32°C. Il y a lieu d'éviter les fonds couverts de sable blanc et les habitats qui hébergent des herbivores. On n'installera pas les exploitations dans la zone des typhons, ni dans des secteurs exposés à de fortes variations saisonnières. L'on doit confier à des unités pilotes le soin de déterminer avec certitude si le site convient à ce genre d'activité.

Deux modes d'exploitation ont été mis au point: (*i*) la culture en filet utilise un engin de 2,5 × 5 m attaché à quatre perches et tendu parallèlement au fond. Les fils en polyéthylène du filet se recoupent en 127 intersections; à chacune de celles-ci on attache un morceau d'*Eucheuma* de 100 g au moyen d'une fine bande en plastique (tie-tie). Lorsque les plantes atteignent de 1 200 à 1 500 g, on les ramène à 500 g en les taillant et ainsi de suite. Les émondes sont séchées au taux de 10:1 et vendues à l'état sec. (*ii*) La culture monoligne, mise au point par les exploitants, a réduit l'entretien à de simples soins de propreté et elle est maintenant la principale méthode utilisée. Toutefois, la densité des végétaux au mètre carré est plus faible que dans le cas de la culture sur filet, et ce mode d'exploitation peut être moins avantageux lorsque les aires de plantation font prime.

Pendant la période 1970–74, la récolte d'*Eucheuma* de culture s'est accrue, passant d'une quantité négligeable (0,6 tonne en 1971) à quelque 10 000 tonnes en 1974, alors que la récolte d'*Eucheuma* sauvage a diminué, tombant de 534 à 75 tonnes. En 1974, l'on comptait 2 249 familles exploitant cette algue dans la région de Tawi-Tawi et de Sulu. La valeur des exportations s'est élevée de US$ 168 210 en 1970 à US$ 4 533 750 en 1974. En 1973, la valeur brute de *E. cottonii* atteignait US$ 20 378/ha par comparaison avec US$ 2 576/ha pour la canne à sucre. L'industrie est en cours de stabilisation. L'on estime que la production annuelle des Philippines est de quelque 3 500 tonnes de produit sec, et que sa croissance est de 10% par an, ce qui représente le total de la demande mondiale de *E. cottonii*.

Les difficultés techniques, politiques et économiques auxquelles on s'est heurté à l'origine pour établir les exploitations de culture des algues aux Philippines ont été largement surmontées. Les principales recherches sur *E. cottonii* ont été effectuées par l'Université d'Hawaï et la société Marine Colloids Inc. De nouvelles recherches s'imposent sur des souches à croissance rapide et à fort rendement en carragénates, ainsi que sur les affections de ces algues. La société Marine Colloids Inc. s'efforce actuellement de réaliser aux Philippines la croissance végétative de *E. spinosum*, que l'on utiliserait à la place de iota carrageenan, mais n'a pas encore trouvé de clone adéquat. La demande totale n'excéderait sans doute pas 4 000 tonnes de produit par an.

Dans le cadre des efforts entrepris pour trouver une autre méthode d'approvisionnement du marché en carragénates, la société Marine Colloids Inc. a effectué depuis l'été de 1974 des expériences sur *E. isoforme*, dans les Florida Keys (Etats-Unis), en recourant à un système de culture en réservoir à fort coefficient de capital. Dans ce système, une amenée d'air provoque une turbulence qui maintient les algues en suspension dans l'eau, leur permettant ainsi de recevoir la lumière solaire et les nutriments en quantité suffisante. Les températures, l'éclairage et la fertilisation sont contrôlés. L'on fait actuellement des comparaisons entre la culture en réservoir et les exploitations sur le terrain. Le programme actuel prévoit deux étapes: (*i*) localisation de souches qui resteront viables pendant toute l'année de manière que l'on puisse entretenir un stock de reproducteurs durant l'hiver, et (*ii*) régénération du stock de reproducteurs à chaque printemps à partir de spores issus de germinations hivernales.

Desarrollo industrial del cultivo de algas marinas: cultivo de *Eucheuma* en las Filipinas y los Estados Unidos

Extracto

El alga roja *Eucheuma cottonii* es una hierba marina que produce carragenano kappa, un estabilizador alimentario que tiene diversas aplicaciones. La facilidad con que se obtienen clones y se reproduce vegetativamente ha hecho posible su cultivo a gran escala en el sur de las Filipinas, donde actualmente se producen grandes cantidades de estas algas. A ello se dedican sobre todo grupos familiares, a los que la compañía Marine Colloids, Inc. ha prestado asistencia, facilitándoles materiales e instruyéndoles sobre las técnicas de cultivo de *Eucheuma*.

En una explotación familiar del sur de las Filipinas de 0,5 ha de arrecife, con líneas de monofilamento de nilón para 7 500 plantas—cada una de ellas con un peso inicial de 200 g, que aumenta a 3 kg a los 90 días—puede obtenerse una cosecha total de 22 500 kg en peso húmedo, de los que se obtienen 2 250 kg de producto seco comercializable. A 1,30 pesos filipinos/kg, los beneficios ascienden a 2 925 pesos filipinos. Los gastos (líneas de nilón, tirillas de plástico, embarcaciones sin motor y pértigas) ascienden a 700 pesos filipinos y los ingresos netos del primer trimestre (en el que los gastos son mayores) son, por tanto, de 2 225 pesos. Los ingresos anuales medios de una familia ascenderían, según eso, a 10 250 pesos filipinos, equivalentes a US$ 1 360 (actualmente, los ingresos familiares en las Filipinas son de unos US$ 400. Granjas de grandes dimensiones parecen poder competir ventajosamente con otros cultivos, incluidos azúcar y coco.

Una granja de *Eucheuma cottonii* debe hacerse en zonas de arrecifes coralinos protegidas contra las tormentas y poco profundas, para que sea fácil colocar las pértigas, pero suficientemente profundas para que queden cubiertas en baja marea. El flujo de agua debe ser bueno y la temperatura anual del agua de 26°–32°C. Han de evitarse los fondos arenosos blancos y las zonas donde viven herbívoros, así como las zonas de tifones o las áreas con grandes variaciones estacionales. Es necesario hacer ensayos para determinar con certeza si el emplazamiento es adecuado.

Existen dos sistemas de cultivo: (*i*) el cultivo en redes, para el que se utilizan paños de red de 2,5 × 5 m atados a cuatro pértigas y colocados paralelamente al fondo. Las líneas de polietileno de la red tienen 127 intersecciones, en cada una de las cuales se amarra con una tirilla de plástico un trozo de *Eucheuma* de 100 g. Cuando la planta alcanza 1 200–1 500 g se poda, reduciéndola a 500 g, y el proceso continúa. El producto obtenido con la poda se seca en proporción 10:1 y se vende seco. (*ii*) El cultivo en una sola hilera, ideado por los acuicultores, ha reducido la manutención, ya que las plantas permanecen más limpias. Es el método más utilizado actualmente. Sin embargo, la densidad de plantas por m^2 es menor que en el cultivo en redes y este sistema podría ser menos ventajoso si las posibles zonas de cultivo fueran escasas.

Durante el período 1970–74, la producción de *Eucheuma* cultivada ha aumentado de una cantidad insignificante (0,6 toneladas en 1971) a un total estimado en 10 000 toneladas en 1974, mientras la producción de *Eucheuma* natural ha disminuido de 534 a 75 toneladas. En 1974 se dedicaban a su producción 2 249 familias en las zonas de Tawi-Tawi y Sulu. El valor de exportación ha aumentado en el período 1970–74 de US$ 168 200 a 4 533 750. En 1973, el valor bruto de la producción de *E. cottonii* fue de US$ 20 378/ha, frente a US$ 2 576/ha en el caso del azúcar. La industria se está estabilizando. Se calcula que el nivel anual de producción de las Filipinas es de unas 3 500 toneladas de producto seco, con un aumento anual del 10%, cifra que representa la demanda mundial total de *E. cottonii*.

Las dificultades tecnológicas, políticas y económicas encontradas inicialmente para establecer explotaciones de algas en las Filipinas se han superado con éxito. Las principales investigaciones sobre *E. cottonii* han sido realizadas por la Universidad de Hawaii y por Marine Colloids, Inc. Son necesarias más investigaciones sobre variedades de crecimiento más rápido, con mayor rendimiento de carragenano y menos expuestas a enfermedades.

Marine Colloids está intentando reproducir vegetativamente en las Filipinas *E. spinosum*, utilizado para la producción de carragenano iota, pero aún no ha encontrado un clono adecuado. La demanda total no sería probablemente superior a 4 000 toneladas al año.

Para encontrar otro sistema de abastecimiento de carragenano, Marine Colloids ha realizado experimentos con *E. isoforme* en los Florida Keys de los Estados Unidos desde el verano de 1974, utilizando un sistema de tanques que requiere empleo intensivo de capitales. Un tanque con agua se agita, introduciendo aire, para que las algas se mantengan en suspensión y reciban luz solar y nutrientes suficientes. Se controla la temperatura, la luz y la fertilización. Se están realizando comparaciones entre plantas criadas en tanques y en su medio ambiente natural. El programa actual incluye dos fases: (*i*) localización de variedades que puedan cultivarse todo el año, de modo que sea posible mantener reservas de semillas durante el invierno, y (*ii*) regeneración de las reservas de semilla todas las primaveras utilizando esporas germinadas en invierno.

1 Introduction

The seaweed, *Eucheuma cottonii*, is a red alga (family Solieriaceae) that produces kappa carrageenan which gives it commercial importance (Fig. 1). Carrageenan is a food stabilizer with various applications. It is extracted from red seaweeds which are harvested commercially in many areas including North America, South America, Europe, and the Far East. *Eucheuma cottonii* represents the first successful farming of red seaweed for the production of carrageenan; a considerable amount of time was necessary to make this venture successful. The development of this industry, its economics, site selection, farming methods, production, and problems concerned with research and development will be described in this paper.

A similar farming development programme with *Eucheuma spinosum* has not shown the same progress. It has been supplemented with a programme to develop a capital-intensive tank culture system for such iota carrageenophytes. Experiences with this experimental programme with *E. isoforme* in the Florida Keys, USA will also be described.



Fig 1. Eucheuma cottoni plant

2 History of development

As early as 1966, experiments were conducted with vegetative growth of *Eucheuma cottonii* in the Philippines. Subsequent work under the direction of the University of Hawaii (Dr. Maxwell Doty) and Marine Colloids, Inc. demonstrated that *Eucheuma cottonii* could be grown vegetatively and had the ability to grow at a rate that would make economic sense. Once this had been accomplished, the transition from experimental and demonstration farms to a commercially significant industry was executed by Marine Colloids (Philippines), Inc.

The system utilized by this firm for rapid expansion of *E. cottonii* farming was the establishment of family- rather than company-owned farms, although some entrepreneurs did establish a number of farms and are producing some *E. cottonii*. In order to get the farms into operation quickly by farmers who had a relatively small amount of capital to invest, the firm distributed free of charge the necessary material to build farms: nets, poles and miscellaneous construction materials. The company also provided several mobile teams to demonstrate the techniques of farming. Expansion was even faster than had been anticipated—through the appearance, through natural selection, of a clone which has been called 'Tambalang'. This clone has demonstrated an unusual flexibility exhibited by, amongst other things: rapid growth; the ability to survive in many geographical areas and thus under different environmental conditions; and a content of excellent kappa carrageenan. This clone multiplies rapidly from one plant into thousands of tons, and most of the *E. cottonii* now grown is this variety.

3 Economics of *Eucheuma cottonii* farming

There are many ways to consider the value to the Philippine economy of seaweed farming and to analyse the benefits for the farmers. Our preferred approach is to show the return to the typical individual farmer who outnumbers by far any other producer and who has been the biggest beneficiary of farm development.

3.1 *Assumptions*

(*i*) Location: Southern part of the Philippines.

(*ii*) Size of farm: One-half ha reef allocated by a municipal council.

(*iii*) Source of labour: Owner-operated, assisted by wife and three children.

(*iv*) Type of farm: A line type constructed from 300–110 lb (135–50 kg) test nylon monofilament lines, 10 m long attached at both ends to poles placed in parallel rows. Each line has 25–30 plants for a total count of 7 500 plants.

(*v*) The harvest: The initial wet weight of the seedling is 200 g which, after 90 days, has grown to 3 kg. The total wet harvest is approximately 22 500 kg from which a dry saleable weight of 2 250 kg is recovered.

(*vi*) Selling price: P.Ps. 1.30/kg. The price has fluctuated but is stabilizing as shown below.

3.2 *Statement of income and expenses*

Typical small farm

	P.Ps.	P.Ps.
Revenues		
2 250 kg at P.Ps. 1·30/kg		2 925
Expenses		
Nylon lines (10 kg at P.Ps. 30/kg)	300	
Plastic tie-ties	100	
Wooden boat (not motorized)	150	
Wooden poles (600 at P.Ps. 0·25 each)	150	
Total expenses		700
Net income (first quarter only)		2 225

Each succeeding quarter produces greater income since expenses are smaller. Net annual income per family is PPs 10 250 or US$ 1 360. Present family income in the Philippines is US$ 400.

Calculations show that larger size farms have the potential to compete very advantageously with other crops, including sugar and coconuts, but the exercise is theoretical at this time because all the production comes from small farms.

3.3 *Site selection*

To establish and maintain a farm, it is necessary to be in a coral reef, adequately protected from storms and shallow enough to facilitate driving poles but deep enough to be covered at low tide. There must be good water flow, and the water temperature should be in the range of 26–32°C on an annual basis with little deviation. White, sandy bottoms must be avoided. Bottoms with some vegetation are generally a good indicator of a nutrient-rich area which is necessary for good growth. Areas known to be well populated with herbivores must be avoided. Farms should not be located in a typhoon belt, or where there is much seasonality, since the environmental parameters vary too much, and *E. cottonii* has difficulty in coping with them.

There is an exactly defined technique whereby an area can be surveyed and, in the final analysis, one must establish test units to determine site suitability with certainty. Marine Colloids has offered a project concerned with such determination to a research institution.

4 Method of farming

Up to now, most of the farms have been located in the south of the Philippines where environmental conditions are stable, and have been sited in a coral reef (as shown in Fig. 2) with an almost total absence of seasonality producing relatively constant environmental conditions. Lately, there has been some success in the farming of *E. cottonii* in areas that do exhibit some seasonality.

Two systems of farming have been developed in this enterprise: (*i*) the net farm; and (*ii*) the line farm, preferred by the farmers because it requires less maintenance.

The method used in a net farm consists of locating under water a basic net unit, 2·5 × 5 m, attached to four poles. The net, made from polyethylene lines, has 127 intersections where vegetative parts of *E. cottonii* are attached (see Figs 3 and 4). After the poles have been driven into the reef bottom, in an area previously tested for growing ability, the nets are strung between the poles parallel to the bottom. The arrangement of nets constitutes modules, and the modules hectares of plantation.



Fig 3. Part of a basic net unit for *Eucheuma* farming



Fig 4. Eucheuma seedlings attached to a net with 'tie-ties'

Seeding can be done on site or before locating the net. The nets are seeded with 100 g pieces of alga by attaching them to the net with a 'tie-tie', a thin plastic strip which does not cut the fronds and allows them to move in the current. Maintenance is required to keep the farm clear from drifting material and grazers, and to replace poor plants. Once the plants have reached a weight of 1 200–1 500 g, they are pruned to 500 g and the process continues. The prunings are dried at a ratio of approximately 10:1 and sold dry.

The farmer provides no control other than good maintenance. Nature provides sea water, water flow, nutrients and



Fig 2. Eucheuma sites in coral reefs in the Philippines

light. Although the technique appears simple, several years of experimentation were required to develop it and technical guidance is necessary to start a new farm and make it profitable.

The farmers have improved upon the method described above by using monolines rather than nets. This reduces maintenance to a minimum; the individual plant keeps cleaner and is free from silt. This method has the disadvantage that the density of plants per m^2 is low; hence, the productivity per unit of area is low in comparison to that of net system. If planting area were at a premium, the difference between the systems would be significant, but at present it is not, hence most farmers have line farms.

5 Production

5.1 *Quantity*

The quantity of wild and cultivated *E. cottonii* harvested during the period of 1970–74 is shown in Table I.

TABLE I
WET WEIGHT HARVESTED (TONS)

Year	*Farmed*	*Wild*	*Total*
1970	—	534	534
1971	0·6	434	434·6
1972	—	503	503
1973	112	522	634
1974	10 000 (estimated)	75	10 075

At the height of production in 1974, there were approximately 2 249 families (4–8 persons/family) farming and producing seaweed in the Tawi-Tawi and Sulu areas. The number of seaweed buyers increased, and a major effort was made by all purchasing companies to break into the procurement of *E. cottonii* which, for the first time, represented a resource available in unlimited quantities.

5.2 *Value*

The export value of *E. cottonii* rose in line with the production, but also rose because the price paid to the farmers had been substantially increased over the previous price paid for wild seaweed. The price of 10–12 centavos/kg in the mid-sixties, and 50 centavos/kg later on, increased with the advent of farming to PPs 3/kg. This attracted many people, as indicated above, to *E. cottonii* farming. As a matter of fact, it attracted too many people.

The export value of seaweed from the Philippines is shown below:

Year	*Export value (US$)*
1970	168 210
1971	195 570
1972	226 350
1973	285 300
1974	4 533 750

Although it is possible to calculate the actual value of production per unit area, it is difficult to calculate the benefits derived or the actual financial gains made by individual farmers. There were so many farmers that very few of them farmed an entire hectare. Most of them laboured in their farms themselves; this makes it difficult, if not impossible, to calculate the labour components. It is safe to say, however, that the farmers have found a new source of wealth which, for them, did not exist before. Calculations by Dr. Doty and Mr. Alvarez indicate that, in 1973, the gross value of *E. cottonii*/ha was US$ 20 378 in comparison with a gross value of US$ 2 576 for sugar/ha.

6 Stabilization

Inasmuch as *E. cottonii* produces pure kappa carrageenan, there is a limited market for the seaweed because the total carrageenan industry can only absorb a finite quantity. Unfortunately, in the early farming stages certain buyers had erroneously reported an unlimited demand for *E. cottonii*. Many farmers were attracted because of these false reports and the high prices that were being paid at the time. Marine Colloids (Philippines), Inc. has continued to buy regularly since the advent of farming and has supported many farmers on a quota system, but some of its competitors have stopped buying and so the number of farmers has decreased and is now levelling off. It is estimated that the annual production level for the Philippines would be approximately 3 500 dry tons with an orderly annual growth of 10%. This represents the total world demand for *E. cottonii*.

7 The problems

There have been three orders of problems in the establishment of seaweed farms in the Philippines. The first were technological, but through the assistance of the University of Hawaii (with the help of US Sea Grants), the problems were eventually overcome and the technique of growing *E. cottonii* vegetatively was successfully developed.

The second problem, no doubt equally as serious, was political ('political' is used in its broadest sense, referring to any relationship with government or representatives of the people at any level). Many problems of such a nature slowed development in the early days, but there has also been excellent co-operation on the part of various governments which has accelerated the farming of *E. cottonii*. Keen understanding and desire on the part of the people's representatives has been a considerable asset in establishing the farms.

Another problem was created by the competitive element that existed in the early days of farming. Some competitors, unwilling to recognize that there was an abundance of seaweed, paid extremely high prices and monopolized the original seedstock. These high prices created a false impression that lured too many farmers into the system. Some of these competitors stopped buying once they had purchased all they wanted; thus, the competitive situation created a false condition for some time, which is now being rectified. There is no doubt that a high degree of competition in the initial stages of a free-farming system has disadvantages, and consideration should be given to some degree of control over developers.

8 Research

All the research that has been made so far on *E. cottonii* was undertaken by the University of Hawaii and Marine Colloids, Inc. An experimental farm was established at Calatagan and one at Zamboanga. There was also a demonstration farm in Sitangkai and monitoring stations in a number of areas.

More research is now required to produce faster growing

strains with higher carrageenan yields. There is also an urgent need for studying the diseases of this alga, such as the most commonly known condition called 'ice-ice'. There is also a continued need for increasing the productivity of the various farms. The private sector does not have the resources to do all this work and it is hoped that assistance will be given for this requirement by publicly funded agencies.

9 *Eucheuma spinosum*

Now that it has been demonstrated that it is possible to grow *E. cottonii* commercially, Marine Colloids (Philippines), Inc. is attempting to grow *E. spinosum* commercially. This red seaweed, which is used commercially for iota carrageenan production, grows in the Philippines in a number of regions and considerable work has already been done at a farm in Ilo-Ilo to grow it vegetatively. So far, no 'magical' clone with a fast growth rate and ability to resist unfavourable conditions has been found. No doubt this would help expand and accelerate the farming of *E. spinosum*.

The largest production now originates in Indonesia. It is expected, however, that with recent successes achieved in the Philippines, a sizeable production will be realized in 1976. Again, the demand for *E. spinosum* is a finite quantity. Only companies in the carrageenan business are in the position to absorb a reasonable quantity, but the total demand would probably not exceed 4 000 tons (dry weight) per year.

10 Tank culture of *Eucheuma*

The success achieved by Marine Colloids, Inc. with *E. cottonii* has stimulated research work oriented toward growing other red seaweeds used in the manufacture of carrageenan, both in labour-intensive and capital-intensive systems in various countries. One such capital-intensive programme is described below.

When it became obvious that the cultivation of *E. spinosum* was not going to be as rapidly successful as that achieved with *E. cottonii*, an alternative method was sought for developing a controlled commercial supply of this raw material. Some measure of success had been achieved in the cultivation of *Chondrus crispus* in Canada, and it was decided to use the same basic mechanical system on a species of *Eucheuma* native to coastal waters of the United States. The species selected was *E. isoforme*. The location selected was the Florida Keys, a chain of islands extending from the tip of southern Florida into the Gulf of Mexico.

The basic cultivation system used was a square tank with a slanted bottom, its water agitated by bubbling air into the deepest part of the tank. This established a circulation pattern strong enough to keep the dense *E. isoforme* in constant suspension. This assured that all plants would receive their share of sunlight and be uniformly exposed to the dissolved nutrients in the sea water.

The variety of *E. isoforme* selected was known through research conducted at the University of South Florida. It showed extremely fast growth in the spring and early summer, with stagnation of growth in the autumn. The plants became reproductive and disintegrated in the autumn and early winter. In the spring, fresh thalli emerged from the holdfasts and new plants were germinated from spores cast by mature plants in the autumn.

As a measure of the progress in tank culture, growth in Marine Colloids' tanks was compared with that in the native population from which the tank culture seedstock was drawn. Since these experiments began in the late summer of 1974 when growth in the field was relatively slow, only the general physical conditions of the plants and their reproductive stage were observed. The plants in the field began showing tetraspore development during September, and by early October were 100% reproductive and had begun releasing tetraspores. By comparison, the plants in the tanks showed little sign of becoming reproductive until well into October, when there was a drastic change in tank conditions. The plants had been maintained with low level illumination at night, and were being fertilized daily. This cycle was interrupted for one day in mid-October and within 24 hours all of the plants in the tank became reproductive and shortly thereafter began to disintegrate as do the field plants. This brought the experiments with this species of *Eucheuma* to an abrupt halt for most of the winter.

The holdfasts in the field began to show new shoots in late January, and by early February of 1975 were 5–10 cm long. A number of these holdfasts were removed and placed in one of the tanks. By the end of February, the plants in the field had grown to about 20 cm while the holdfasts in the tanks showed virtually no growth. The young shoots in the tanks remained healthy in appearance, however, and photosynthesized at a rate similar to that of the field plants. Some of the 20 cm plants from the field were harvested and placed free-floating in growth tanks. Moderate growth was obtained when the plants were fertilized during March, but in the absence of added fertilizer the plants lost weight. During this same period, the field plants, with only the normal ambient nutrients, were beginning their typically rapid spring growth. During April and May, the plants in the tanks with low levels of fertilization kept pace with the field plants; tank plants not given any additional fertilizer lagged behind the others. As the water temperature in the Keys approached its summer peak, plant growth slowed, both in the tanks and in the field.

During the late summer—to help understand the experience of the previous year in temporarily arresting the onset of reproduction in the plants—an attempt was made to induce reproduction by dropping the water temperature prematurely, and by artificially shortening the length of day. Neither of these moves was successful, and during September 1975 the plants in the tanks became reproductive on the same schedule as the plants in the field.

Based on these experiments a two-step programme for tank culture of *Eucheuma* has been initiated. The first step is to locate strains which remain viable throughout the year. Such populations are known in Florida coastal waters. This will allow maintenance of seed-stock through the winter, even if the growth is insignificant during that period, and harvest only during the six month growing season.

The second approach is to regenerate the seedstock each spring from spores germinated during the winter. A programme is underway to develop techniques for operating a winter sporeling nursery. Through these efforts, it is expected that the farmed *E. spinosum* will be supplemented with tank-cultured material until one or the other reaches a stage where the carrageenan industry can be assured of an adequate supply.

Chapter VI Aquaculture in Raceways, Cages and Enclosures

Selection of Sites and Design of Cages, Fishpens and Net Enclosures for Aquaculture

P. H. Milne

Abstract
The engineering developments of the last decade in the design and construction of facilities for aquaculture have considerably improved its economic prospects.

This review of engineering techniques for aquaculture discusses the problems of site selection and analysis with special reference to the requirement of pollution-free water and its abstraction rate. The design and construction of facilities used for aquaculture are described for fishpens, net enclosures and cages. The various types of ponds and their advantages of adaptability are emphasized. Examples are given of sea enclosures, both intertidal and sublittoral, the latter being either rigid or flexible frameworks. The diversification throughout the world of materials and techniques for fish cage construction, using rigid and flexible frameworks, are considered with their advantages and disadvantages.

The need for careful monitoring of the surrounding environment in marine aquaculture is most important since sea enclosures or cages may affect the hydrography of the area, and marine fouling will alter the water currents.

The advances made in the last decade indicate that the FAO projected requirement of 40 million tons of fish and shellfish will be met from aquaculture by the year 2000.

Choix de sites et conception de cages, de parcs à poisson et d'enclos en filet pour l'aquaculture
Résumé
Les progrès techniques survenus durant la dernière décennie dans la conception et la construction de dispositifs servant à l'aquaculture ont considérablement amélioré les perspectives économiques de cette activité.

Dans le présent document consacré aux techniques de l'aquaculture, on envisage les problèmes du choix et de l'analyse du site du point de vue de l'eau, qui doit être exempte de pollution, et de son taux d'extraction. La conception et la construction des dispositifs servant à l'aquaculture (parcs à poisson, enclos en filet et cages) font l'objet d'une description. L'on souligne les avantages que présentent divers types d'étang du point de vue des possibilités d'adaptation. Le document donne des exemples d'enclos marins, tant de type intercotidal que sublittoral, ce dernier étant constitué de cadres soit rigides soit flexibles. On examine la diversification des matériaux et des techniques utilisés pour la construction de cages à poisson, selon qu'il s'agit de cadres rigides ou de cadres flexibles, en indiquant leurs avantages et leurs inconvénients.

La nécessité d'une surveillance continue de l'environnement est particulièrement importante dans l'aquaculture marine étant donné que les enclos ou les cages peuvent agir sur l'hydrographie de la région, et que l'encombrement du milieu marin modifiera les courants aquatiques.

Les progrès réalisés pendant la dernière décennie permettent d'espérer que l'on atteindra les objectifs fixés pour la production de l'aquaculture d'ici l'an 2000, à savoir 40 millions de tonnes de poissons, de mollusques et de crustacés.

Selección de emplazamientos y diseño de jaulas, enrejados y cercos de red para la acuicultura
Extracto
Los progresos de las técnicas de diseño y construcción de instalaciones para la acuicultura durante el último decenio han mejorado considerablemente las perspectivas económicas de esta industria.

En el presente trabajo se estudian los problemas que plantea la selección y análisis de emplazamientos adecuados, atendiendo especialmente a la necesidad de disponer de agua no contaminada y al porcentaje de extracción. Se describen las técnicas de diseño y construcción de corrales, cercos de red y jaulas y se indican los diversos tipos de estanques y sus ventajas desde el punto de vista de la adaptabilidad. Se dan algunos ejemplos de recintos marítimos tanto en zonas que quedan descubiertas entre marea como en zonas sublitorales; en este último caso se tiene en cuenta el empleo de armazones rígidos o flexibles. Se examinan los diversos materiales y técnicas utilizados en todo el mundo para la construcción de jaulas para peces, con armazones rígidas o flexibles, señalando sus ventajas y desventajas.

En la acuicultura en aguas marinas es extremamente importante examinar atentamente el medio ambiente, ya que la construcción de recintos o jaulas podría influir en la hidrografía de la zona y la incrustación marina causada por ellos alterará las corrientes.

Los progresos realizados en el último decenio permiten esperar que las proyecciones de la FAO de que se lleguen a obtener 40 millones de toneladas de peces y mariscos de la acuicultura podrá ser realidad para el año 2000.

1 Introduction

The success of commercial aquaculture enterprises depends not only on biological advances but also on site selection and the development of engineering techniques for the design and construction of facilities.

Commercial aquaculture may be defined as a means to promote or improve the growth, and hence production up to marketable size, of freshwater, brackishwater and marine finfish and shellfish for commercial use by protection and nurture on leased or owned areas. Thus the prospective farmer, having determined a suitable area for development, must also obtain legal access to the land, sea or lake shore and lake bottom or sea bed necessary for successful operation of his farm.

The design aspects of an aquaculture farm depend on the species, since for finfish it is necessary to herd the stock in tanks, cages or enclosures, whereas for shellfish either hanging or seabed techniques can be used.

The Department of Civil Engineering in the University of Strathclyde, Glasgow, has been associated for ten years with the development and construction of facilities for aquaculture (Milne, 1972b) not only in the United Kingdom and continental Europe (Milne, 1974c) but also in the Far East (Milne, 1974a). In the early sixties when British aquaculture started to gather momentum, envious eyes were often cast abroad at spectacular engineering enclosure techniques and there were early ideas for constructing large underwater ranches for fish farming. British fish farmers and researchers, however, actually started on a more cautious footing with considerable background research into site selection and materials selection for the design of suitable holding facilities for aquaculture.

2 Site selection and analysis

At a freshwater fish farm supplied by a river it is essential to ascertain the maximum and minimum yearly flow rates to find the proportion which may be abstracted for use, depending on the regulations of the local water authorities. The size of the fish farm will then depend largely on the minimum flow rate. If, however, there is an adjacent freshwater lake or loch, recourse may be made to pumping, thereby allowing the fish farm to expand at a later date. There are two such fish farms in Scotland on the shores of Loch Awe and Loch Ken. If a prospective fish farmer already owns a site where the minimum flow rate is insufficient for a normal one-pass system, he also has the alternative of a closed-cycle system whereby he may recycle the

water after treatment. Land-based fish farms allow maximum supervision but the critical factor in site selection is the permissible freshwater abstraction rate. Prior to acquisition of the site, the quality of the water should be determined by regular sampling to check on its basic constituents as well as the presence of toxic chemicals polluting the river upstream of the fish farm, and here the whole catchment area should be checked for possible pollutants (Webber, 1973).

The marine fish farmer does not have the same problem of flow rates since there is an abundance of sea water round our coasts. Carstens (1974) has expressed the opinion that mariculture is most likely to succeed on the Pacific coast north of Seattle, the west coast of Scotland and the Norwegian coast. However, the pollution problem is still very real from rivers and estuaries near centres of population, hence the rapid development in ten years of over forty fish farming organizations on the west coast of Scotland where there is little industrial development. This area, with a long indented coastline, giving sheltered sea lochs and (at present) clean unpolluted water thus offers ideal conditions for fish farming. In the middle and late sixties the University of Strathclyde had a 21 m research vessel, which was used to carry out extensive hydrographic surveys on the west coast of Scotland to examine potential fish farming sites. At one of these, Ardtoe, the White Fish Authority chose in 1965 to site a Marine Cultivation Unit (Milne, 1972). Marine farms may be sited (Fig. 1) either on the shore with a pumped seawater supply, in the intertidal zone, in the sublittoral zone (Milne, 1970) or offshore with floating or seabed cages (Milne, 1974b). The quality of the sea water at the site must also be ascertained by regular sampling and hydrographic surveys are required to determine annual variations in salinity, temperature and dissolved oxygen content, as was carried out on the west coast of Scotland (Milne, 1972a).

Current measurements should also be taken to ensure sufficient tidal flow to carry away faecal and waste deposits from the fish farm. For sublittoral enclosures or seabed cages, an underwater survey of the sea bed (Milne, 1973) should be made to check on the seabed conditions. Such an underwater survey can also provide valuable information on the marine life in the area and help clarify the suitability of the area for fish farming.

3 Construction techniques

Construction techniques vary throughout the world, depending on the type of farm and species. In fish farm design it is essential to gear the facilities and materials to local supply and conditions, and facilities must be capable of flexibility for mobility and expansion.

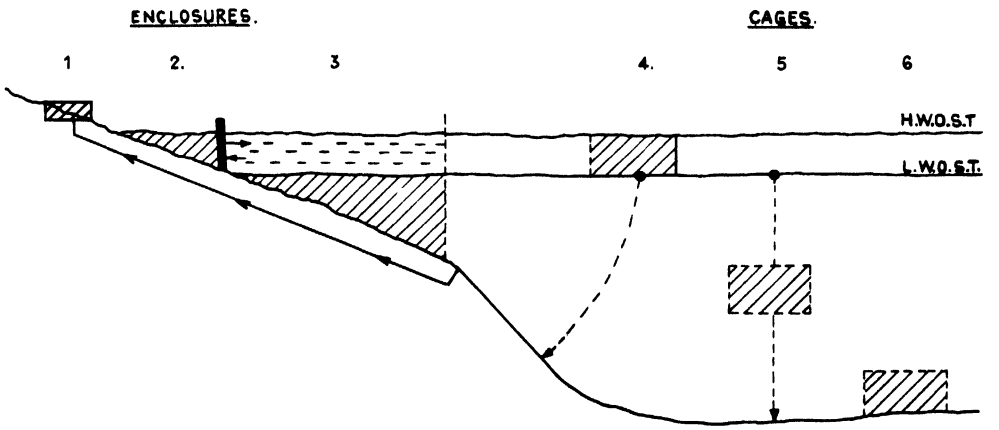
3.1 *Shore facilities*

Dealing first of all with shore facilities, countless earth ponds have been excavated for trout farming in Europe, especially in Denmark. These techniques are also used in Scotland, but—as in other countries—the earth sides of the ponds require considerable maintenance and several operators are now finding polythene, rubber and butyl liners beneficial. In Iceland, where large sheets of this material are at present unobtainable, the pond bottoms are provided with a concrete screed to ease cleaning (Milne, 1975). The American concrete or brick raceway has also been adopted on many British fish farms.

Hatchery facilities are fairly standard the world over, using either stainless steel or concrete troughs for fry and fibreglass tanks for fingerlings. One new hatchery in Iceland has had its tanks moulded in concrete (Milne, 1975). The use of portable facilities is highly desirable at an early stage in a commercial development to allow for design and location changes. For example, rubber-lined tanks with a galvanized steel frame have been in use for six years in Japan for abalone (*Haliotis*) farming and are now in their third location in the same compound (Milne, 1974). Farmers, before stipulating concrete for facilities, should be absolutely certain of their requirements, since many large areas of concrete ponds are lying derelict. Fibreglass tanks, in one piece or made from panels bolted together, and extruded polystyrene tanks are thus ideal for new developments.

3.2 *Sea enclosures*

The development of sea enclosures in Britain and continen-



MARINE FISH FARMING

DEVELOPMENT FROM SHORE TANKS TO SEABED CAGES AND ENCLOSURES.

Fig 1. The six possible zones for aquaculture: 1. shore; 2. intertidal; 3. sublittoral; 4. surface floating; 5. mid-water, and 6. seabed

tal Europe in both the intertidal and sublittoral zones has stemmed mainly from the large sea enclosures constructed in Japan for the farming of the finfish 'yellowtail' (*Seriola quinqueradiata*).

3.2.1 *Intertidal.* An intertidal enclosure, constructed in the twenties lies at Adoike near Takamatsu in the Inland Sea in Japan. Ardtoe in Britain (Fig. 2) was built on similar lines for the White Fish Authority in 1965 but on a much smaller scale. Both enclosures by their nature suffer from some loss of circulation in remote parts of the pond away from the sluices (Milne, 1971). Since the present cost of construction for concrete seawalls or stone-pitched embankments is excessive, few intertidal enclosures are now being built.



Fig 2. Intertidal enclosure at Ardtoe in Scotland constructed for research into flatfish culture by the White Fish Authority in 1965

3.2.2 *Rigid structures.* The Japanese sublittoral netting enclosures of the sixties also covered vast areas, but provided divers with a major problem since the nets required changing at regular intervals. Some 73 net enclosures have been constructed in the Inland Sea in Japan but not all of these have been successful since some were poorly sited in areas with little water exchange, due to tidal ranges of less than 1 m. Others used standard fishing nets not intended for sustained immersion in the sea; these fouled with marine oranisms to such an extent that circulation was restricted and the nets damaged by water currents, combined with wind and wave action.

The more modern successful net enclosures have been positioned only after extensive hydrographic studies to ensure sufficient water exchange. The design and selection of materials for the netting structure and net has also improved. One such new net enclosure was constructed in 1968 at Sakaide near Takamatsu, enclosing an area of 8 ha (Fig. 3). At Sakaide, galvanized chain-link mesh was used for the main fish netting to reduce marine fouling and subsequent maintenance and cleaning. In 1973, the annual harvest was 100 000 yellowtail, each of approximately 300 g weight.

In the mid sixties considerable interest was aroused in Britain by the Japanese development of net enclosures, and members of the Department of Civil Engineering at Strathclyde University subsequently received a research grant from the Natural Environment Research Council to study the design and construction of sublittoral net enclosures.

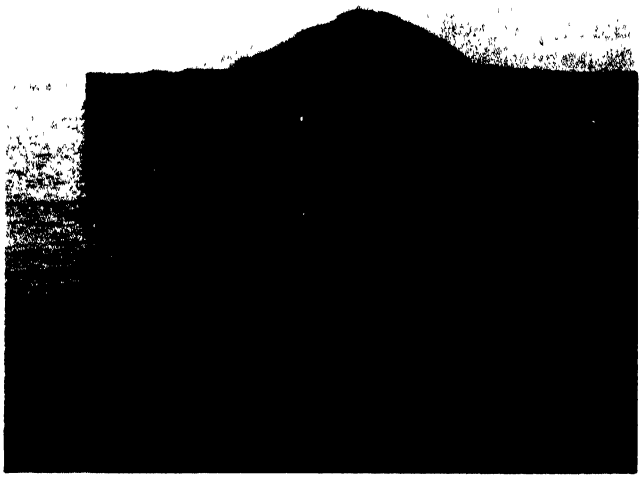
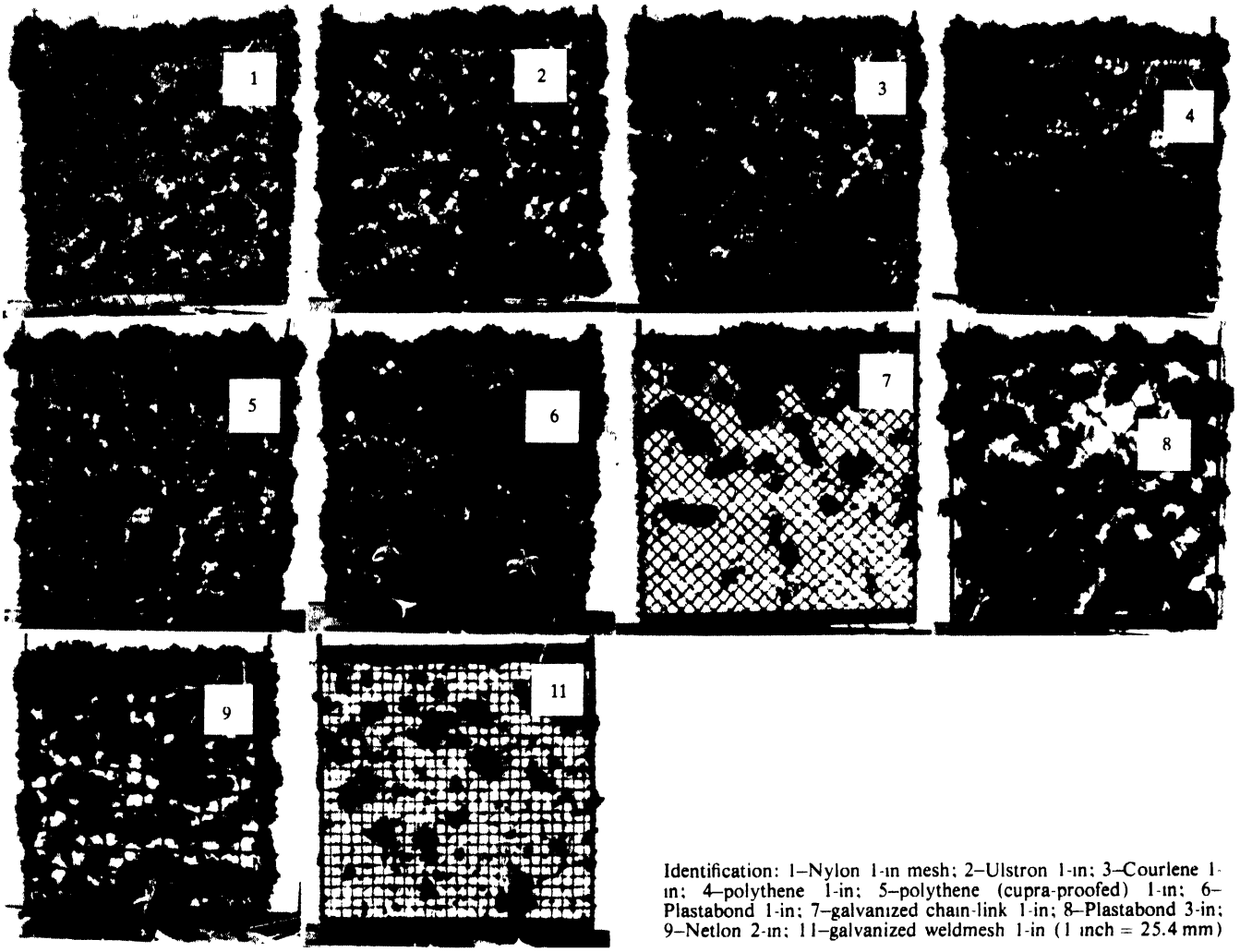


Fig 3. A successful yellowtail farm covering 3·5 ha at Sakaide near Takamatsu in Seto Inland Sea, Japan

After an initial study of marine fouling of various types of fish nets (Fig. 4) on several sites on the west coast of Scotland, galvanized weldmesh and galvanized scaffolding were chosen as the most suitable materials for the construction of two 12 m square fish enclosures at Faery Isles, Loch Sween in Argyll, in April 1969 (Fig. 5). Where access catwalks are required above the high water level, areas with small tidal ranges are preferred, such as in Loch Sween where the tidal range is 1·5 m.

These enclosures have had an interesting career. Designed initially for research purposes, for the first two years research was carried out by the Scottish Marine Biological Association and the Department of Agriculture and Fisheries for Scotland. The enclosures were then leased to the White Fish Authority for two years to complement their facilities at Ardtoe and Hunterston. At the completion of this research programme the enclosures were sold to a commercial company, Joseph Johnston and Sons Ltd., and stocked with Atlantic salmon (*Salmo salar*). A diving inspection round the enclosures after five years showed that the original galvanized mesh netting was still in good condition.

When new sublittoral enclosures were required by the White Fish Authority at Ardtoe in 1972, their experience with the Faery Isles fish enclosures enabled a re-assessment of the basic design and construction of sublittoral enclosures. Due to the ease of erection and subsequent maintenance and cleaning, galvanized scaffolding and weldmesh were again chosen. However, at Faery Isles the corners of the enclosures were curved to a 1·5 m radius on advice that square corners were not desirable in a fish cage. Subsequent work in harvesting fish from the enclosures showed that the round corners presented problems in herding using sliding screens, so square corners were chosen for the two 7 × 3 m enclosures constructed at Ardtoe in April 1972. One other problem with enclosures stocked at high density is the attraction of predators such as seabirds and otters. To combat this, surface covers, again of galvanized weldmesh were provided at catwalk level. Since these enclosures were designed for the retention of plaice (*Pleuronectes platessa*) and turbot (*Scophthalmus maximus*), a very small mesh with a $\frac{1}{2}$ in (13 mm) clear spacing was used. The surface covers were made with a 2 in (51 mm) spacing for lightness and were hinged down the centre of the enclosure for ease of access.



Identification: 1–Nylon 1-in mesh; 2–Ulstron 1-in; 3–Courlene 1-in; 4–polythene 1-in; 5–polythene (cupra-proofed) 1-in; 6–Plastabond 1-in; 7–galvanized chain-link 1-in; 8–Plastabond 3-in; 9–Netlon 2-in; 11–galvanized weldmesh 1-in (1 inch = 25.4 mm)

Fig 4. Marine fouling test panels, each 0·66-m square from Loch Sween, Scotland, after ten months' immersion

Having carried out basic research into the design, construction and hydrography of sublittoral net enclosures, it is rewarding to see successful enclosures of this type being built throughout the world.

A similar technique using bamboo poles instead of galvanized scaffolding has been used at Laguna de Bay in the Philippines (Fig. 6). Initially in 1970 the Lake Laguna Development Authority constructed a 40 ha pilot project for farming milkfish (*Chanos chanos*) in a water depth of 1·5 m. Although the lake fishermen were sceptical of the success of such a project, the acceptance of change has now been recognized, and by 1973 some 1 500 ha of bamboo enclosures were in use.

Sublittoral enclosures for Atlantic salmon farming have

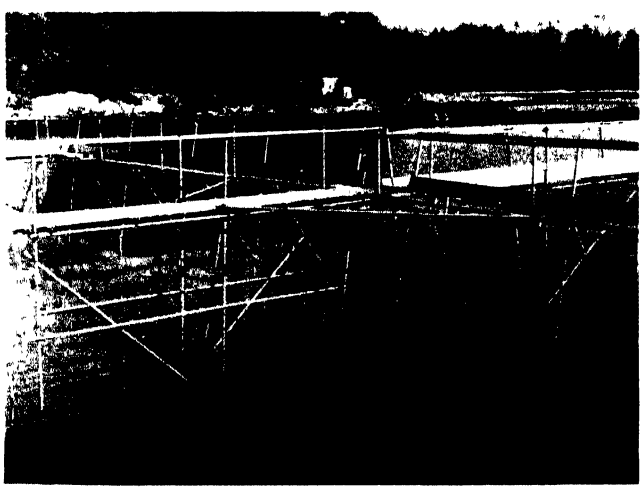


Fig 5. Galvanized scaffolding and galvanized weldmesh used to form two 12-m square fish enclosures at Faery Isles, Loch Sween, Scotland



Fig 6. Bamboo barricades constructed for milkfish farming in Laguna de Bay near Manila in the Philippines

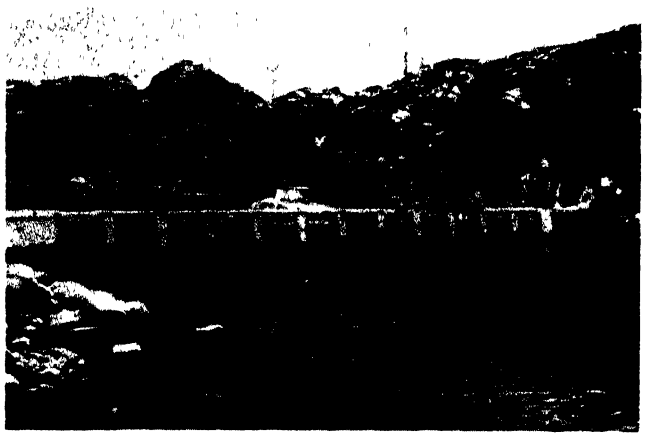


Fig 7. Concrete sublittoral barrier with aluminium sliding screens across a Norwegian fjord for Atlantic salmon farming

also been built in Norway using more substantial concrete structures with aluminium mesh screens. Two such enclosures were constructed for A/S Mowi at Flogøykjölpo and Voløkjölpo near Mövik, just west of Bergen. The first enclosure was built in 1969 covering 1·2 ha; the second was built in 1970 covering 3·5 ha. The farming potential of these two salmon enclosures is hoped to be more than 1 000 tons (Fig. 7).

The most recent sublittoral enclosure to be constructed in Britain was installed for the White Fish Authority in the north channel of Loch Moidart in 1974. This enclosure is of extreme interest since the tidal range is 5 m and a structure similar to the Faery Isles enclosures would have presented large areas of netting for wind and wave attack. Such large design loads, not to mention the considerable variation between the high and low water volumes, would have been troublesome. A compromise has, however, been reached by building a 40 m^3 capacity cage with its upper surface just above the low water neap tide level, thus allowing access to the enclosure at low tide each day. The cage has proved its stability by weathering winter storms and has now been stocked at a low density for a bio-engineering study of the fish husbandry techniques required for succesful operation of this type of enclosure.

3.2.3 *Flexible structures.* Where a buoyed fish net enclosure is designed as a bag net with a bottom net, even though it may rest on the bottom, it has been discussed as a cage. Most buoyed fish enclosures are of this type, but there is a limitation on size, the largest known one being in Japan with a diameter of 55 m. A design project for sublittoral enclosures in the Philippines in 1973 considered using either a Japanese or Faery Isles piled enclosure technique. However, due to the considerable depths of soft silt in Laguna de Bay, neither of these methods were suitable due to the extreme lengths of piling required to provide a stable structure to withstand typhoon conditions. Possible variations from the piled structures were floating cages or floating net enclosures. Since an alternative technique to the existing bamboo enclosures, covering 1 500 ha, was required, the solution was to design a floating net enclosure (Fig. 8), and a 10 ha trial enclosure is to be built in 1975 (Milne, 1974b; Delmendo and Gedney, 1976).

In the Philippines, to be economically viable, any fish enclosure system must be capable of being constructed by local fishermen from their local facilities. The heaviest materials specified for this floating net barrier were the concrete block sinkers weighing 500 kg at 30 m centres. The weights will be placed in position from a small floating barge and a chain-link riser chain provided from the sinker for attachment to the net to allow for settlement in the soft sediment.

Since Filippino nylon nets last only a year, a Japanese $\frac{3}{8}$in (9·5 mm) nylon net was specified for strength, antifouling properties and long life (3–5 years). The average depth of Laguna de Bay at low water is 3 m and at high water is 5 m. A 7·5 m height of net was therefore specified to allow for billowing due to water current and wave motion. In the previous bamboo corrals the fish netting was taken above the surface to prevent fish escape by jumping, but this is not possible with a floating net. A 2·5 m wide floating horizontal section is therefore attached inside the enclosure on the surface to prevent the milkfish from jumping over the

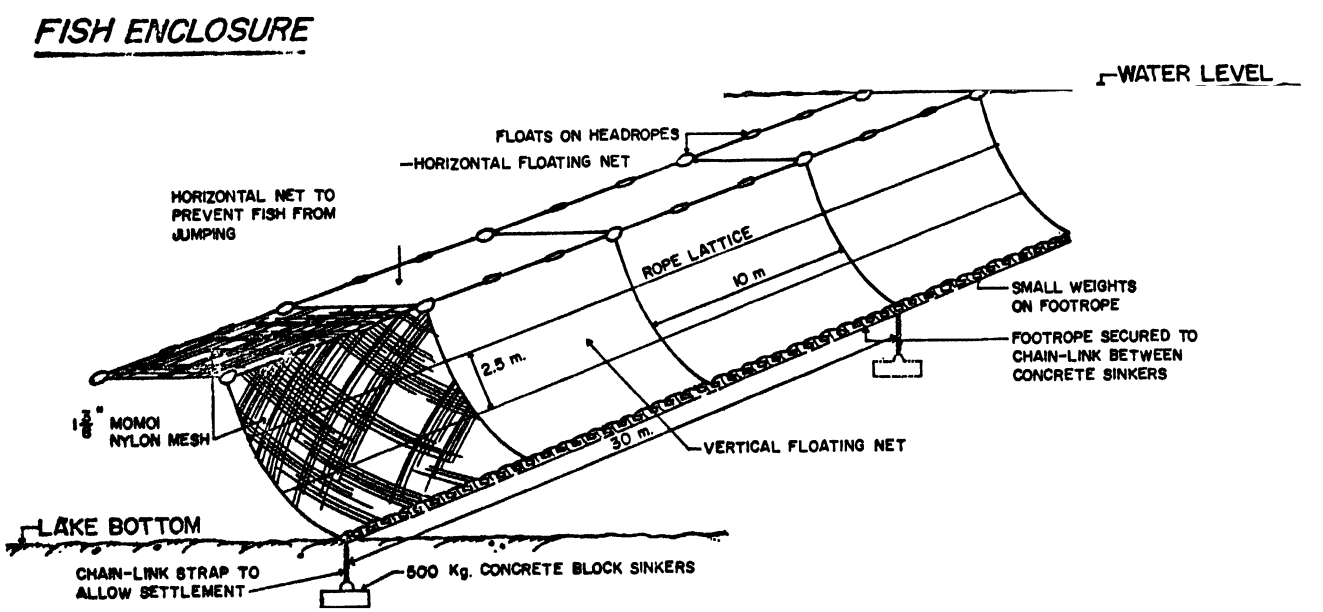


Fig 8. A floating fish net barrier design for providing large enclosures for milkfish farming in Laguna de Bay, Philippines

vertical net. This section of netting also acts as an assurance against the lake water level rising to 7 m (the 100 year flood condition, which occurred in 1972) since the net will rise into a vertical position thus maintaining a fish seal. This technique of using horizontal floating net sections has already proved successful for farming Pacific salmon (*Oncorhynchus*) in Japan as described in section 3.3.2.

To spread the load of the forces due to water movement and wave action from the fishing net down to the sinkers, a latticework of nylon ropes is provided. In practice, the complete latticework of nylon ropes, nylon netting and chain-link footrope will be assembled on the shore, ferried to the site on a floating barge, lowered into position and connected to previously placed and buoyed sinkers. The only underwater work involved will be the attachment of the chain-link risers from the sinkers to the chain-link footrope. One considerable advantage in a floating enclosure system is that there is no need for any allowances for wind forces on the exposed sections of netting and structures, where typhoon damage is normally caused. Another advantage is the ease of access for boats, since no boat locks are required and smooth-bottom boats may slide over the net, provided the engine's propeller is lifted clear or shielded with a fairing. With such a flexible floating net enclosure technique, this method can be applied universally to any part of a shore line, thus simplifying design and construction.

3.3 *Floating fish cages*

The last decade has seen a considerable expansion in the use of floating facilities for aqua-farming, and this has increased the potential development of aquaculture throughout the world. There are three very important advantages in the use of floating techniques. Firstly, they can be used in areas where the sea bed is unsuitable for traditional shellfish farming; secondly, by using off-bottom methods predators can be more easily controlled with less loss of stock; and, thirdly, if threatened by water pollution the stock may be towed out of danger.

3.3.1 *Cages with rigid framework.* The technique of farming fish in floating cages in Japan has developed rapidly over the last decade. Originally nylon bag nets were suspended from a bamboo framework supported by either old steel drums or polydrums. The sizes of these cages grew rapidly from 2 m square up to a normal 7–9 m size with a maximum of 14 m. Unfortunately, at the same time as the fish harvest was increasing so was the deterioration of the bamboo poles and the fouling of the polydrums. To combat the latter, polythene bags are now used to cover the drums and these are replaced each year rather than cleaning the drums themselves. The bamboo poles must, however, be replaced every 2–3 years. The fish bag nets also foul during the summer months, restricting the water flow and thus require changing and cleaning regularly—one set of yellowtail fish cages at Shirahama in the Inland Sea has its nets changed every eight days, although in most cases once a fortnight is sufficient.



Fig 9. Circular galvanized steel collar, 14 m diameter, with galvanized chain-link bag net, supported by polydrums, for farming yellowtail in Inland Sea, Japan

The continuous replacement of the bamboo poles due to their deterioration in sea water has caused concern. Some yellowtail farmers, especially at Sakaide have now started to use galvanized steel collars for their floating fish cages. These collars are fabricated from four 'L' sections of galvanized structural scaffolding bolted together to give a 7 m square framework. This technique offers considerable scope to the prospective fish farmer who does not wish his capital costs to escalate.

The problems in Japan of deterioration of bamboo poles and fouling of netting have been studied by Professor T. Harada, Director of the Fisheries Laboratory of Kinki University at Shirahama. To provide a rigid collar for supporting the fish retention bag net, Professor Harada has now transferred his allegiance from indigenous materials to galvanized steel, which is much stronger and has a much longer life than the bamboo, but he is still using polydrums sheathed in polythene bags. These new cages are circular and are constructed in two sizes. The small 8 m diameter cages 6 m deep were used for the first time in 1972, followed by the use of larger 14 m diameter cages 7 m deep in the spring of 1973 (Fig. 9).

To minimize the problem of maintenance, Professor Harada is also using galvanized wire mesh to retain the fish. With such a deep cage it is impracticable to use a rigid weldmesh, and hence flexible chain-link galvanized wire has been chosen. The foot of the cage is formed by a circular galvanized steel collar and at harvest time this collar is raised to the surface. The only drawback to the use of chain-link mesh is that there is considerable wear between the interlinking meshes due to tidal action and wave motion. It is therefore proposed to replace the chain-link mesh every year for safety. Although the chain-link is more expensive at the outset than the nylon, there are considerable savings in maintenance since the net requires no cleaning, and only requires changing once a year rather than every eight days in summer and every 20 days in winter. There is also less loss of fish since handling is considerably reduced.

The use of rigid collars with catwalks has advantages in the accessibility and mooring of the cages. Cage design in Britain has evolved slowly in the last ten years, and cages used by Marine Harvest Ltd. (a subsidiary of Unilever) at Loch Ailort, and the White Fish Authority at Loch Moidart are similar in the provision of catwalks for access. These cages, like one recently constructed for Joseph Johnston and Sons for farming salmon in Scotland, have been cages with rigid mesh sides and a structural framework requiring considerable buoyancy. These stronger cages have been designed for more exposed locations with appreciably

larger tidal ranges, 4–5 m, than the sheltered waters of the Inland Sea in Japan with a tidal range of only 1 m. To try and reduce weight, the recent Joseph Johnston cage employed galvanized scaffolding tube for easy site erection and modification. This technique is suitable for the construction of cages up to 6 m cube, providing a very robust and corrosion-resistant cage (Fig. 10).

For access for feeding and maintenance, cages with rigid collars and rigid sides can be moored side by side. On a large farm where water circulation is important they may be moored either round a spider framework to take up to six cages, as used in Loch Ailort, or along either side of a central floating catwalk.

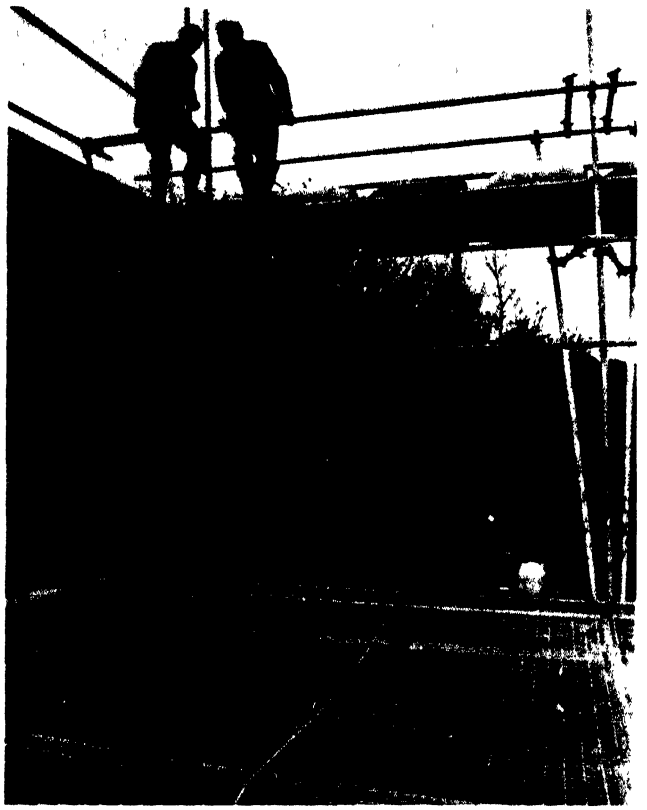


Fig 10. Floating fish cage for Atlantic salmon farming under construction in Scotland in 1973. Galvanized scaffolding and weldmesh were used for the framework and cage, measuring 6 × 6 × 3·6 m

A second generation of rigid catwalk cages with suspended bag nets, similar to the Japanese cages for yellowtail, are now appearing in Scotland as fish farmers attempt to reduce cage weight whilst providing sufficient buoyancy and keeping down associated costs.

One such cage, designed by Dr. P. J. Landless of the Scottish Marine Biological Association at Oban (Landless, 1974), has been used with great success in Dunstaffnage Bay in Scotland for research purposes. This cage has created considerable interest since it will hold 1 ton of fish at 20 kg/m^3 in a bag net measuring 4 × 4 × 3·1 m. Like the Joseph Johnston cage described above, this cage also utilizes an upper framework of galvanized scaffolding tube supported by expanded polystyrene floats. Once the tubing is cut to size, the raft takes only two hours to assemble. Due to the lightness of such a structure, only end floats are required, thus improving the water flow and circulation. One considerable advantage is that they are light and thus the nets can be cleaned and hauled easily by two men. The floating catwalk can also be brought ashore for maintenance.

As the size of a fish cage increases it becomes more difficult to design a suitable rigid structure to maintain the shape of the cage and still act as a catwalk for access. The largest known cage of this type is a 50 × 12 m Pacific salmon cage at Reservation Bay near Anacortes, Washington, USA, where polystyrene modules were connected together with continuous steel cables (Hunter and Farr, 1970). Such structures require careful designing to withstand the combined effect of wind and wave action. A desire to minimize these surface effects has led to the development of buoy-supported, or flexible net cages.

3.3.2 *Cages with flexible framework.* Research has been carried out for some time in Japan into the use of buoyed bag nets for fish farming. Numerous small surface cages, 6 m cube, have been used for the commercial farming of yellowtail, and Professor T. Harada has successfully used 20–30 m buoyed fish cages at Shikoku near Shirahama.

An even larger surface cage, 55 m diameter and 25 m deep, has been used in Japan for holding chum salmon (*Oncorhynchus keta*). The cages are installed in Lake Saroma on the northeast coast of Hokkaido in northern Japan. To prevent the salmon from jumping over the top of the vertical net, a 3 m length of floating horizontal net is stretched round the periphery inside the cage. The base of the bag net is allowed to lie on the sea bed, and when the nets are changed every six months for cleaning, the centre of the old bag net is raised and the new net spread round the outside and sealed. Then the fish are transferred and the old net lifted out. Such a technique is only feasible if marine fouling is not severe and only a few net changes are necessary each year.

Another cage utilizing this flexible framework technique is the midwater fish cage used by the Hiketa Fishermen's Co-operative Association at the east end of the Inland Sea. These fish net cages are 9 m square by 8·25 m deep, with a buoyed feeding neck. They are fixed to a buoyed rope lattice which in calm weather is normally suspended 1·5 m below the surface, but can be dropped to 6 m during typhoons. The cages are normally grouped in facilities of 10–12 cages. The tensioning cables for such flexible cages must be very secure as Dømsea Farms in Puget Sound, Washington, USA, had some early problems with their 50 × 50 × 25 ft (15·2 × 15·2 × 7·6 m) cages (Anon., 1972).

4 Aquaculture maintenance

After construction of a farm it is essential to ensure that the water supplies are unaffected by general fouling. In sea water this is of special importance as the cages or enclosures may change the environment. After construction of the Faery Isles fish enclosures in Scotland, already mentioned, numerous hydrographic surveys and current measurements were carried out to assess the effect of the netting on the water flow (Milne, 1971). It is thus essential to have clean netting and this requires a knowledge of the expected

marine fouling on the netting. Site fouling tests carried out on different materials before the selection of the ultimate material may save considerable time on maintenance and cleaning, as differential growth rates have been observed in Scottish tests (Milne, 1975b).

Predator control is another problem. For shellfish the use of off-bottom culture techniques will prevent starfish and crab losses. For surface cages and enclosures, some form of high level netting is essential to keep out birds.

5 Conclusions

In the last five years the total world production from aquaculture has doubled to over 6 million tons per annum. To provide sufficient food for world populations, FAO projections indicate a requirement by the year 2000 of 40 million tons per annum of finfish and shellfish from aquaculture. This target is by no means unrealistic when one considers the advances made in aquaculture during the last decade. This provides a genuine challenge to those who are prepared to tackle the biological, environmental, engineering and managerial factors involved in running a successful and financially rewarding enterprise.

6 Acknowledgements

The Department of Civil Engineering at the University of Strathclyde, Scotland, are thanked for their assistance in supporting the author's research. Others whose aid or work in this field is not mentioned will, it is hoped, understand the difficulty of including all the references one would wish in such a short review.

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Floating Cage Culture of Fish in the Lower Mekong Basin

V. R. Pantulu

Abstract

The traditional cage culture techniques in Kampuchea and the adaptations of these techniques used in the southern part of Viet Nam are described. In Kampuchea, cages are made of bamboo poles and splints which are often reinforced with wooden planks and beams. Cages vary in size from 40 to 625 m^3. The major genera cultured include *Pangasius*, *Clarias*, *Channa* and *Oxyeleotris*. Fry for stocking are obtained from natural sources and fish are fed with local vegetable or animal products. According to a survey conducted in 1969, there were 946 cages operating in Kampuchea.

Cage culture was initiated in the southern part of Viet Nam by immigrants from Kampuchea, although the technique is rapidly gaining popularity with Vietnamese fishermen and entrepreneurs. There are now an estimated 10 000 cages operating in the southern part of Viet Nam. Cages vary in size from 60 to 181 m^3 and have an average life of 10 years. The most important genera cultured include *Barbus* and *Leptobarbus* (in 61% of the cages), *Pangasius* (20%), and *Channa* (18%). Fry are collected from natural sources with weirs, traps, seines and dip nets, and stocked at densities varying from 80 to 361 fry/m^3. Fish are fed with local vegetable and animal products and the average feed conversion rate is 4·0. Period of culture ranges from 9 to 11·5 months depending on the species, yielding a harvest of 3 000–25 000 kg/cage/year valued at US$ 2 500 to US$ 31 500. Operating costs for cage culture in southern Viet Nam exceed capital investment by 120 to over 300% while net returns on total costs are generally between 12 and 44%.

Cage culture is not subject to the many inherent problems of pond culture and it is recommended that more emphasis should be placed on developing sound cage-culture practices.

Pisciculture en cages flottantes dans le bassin inférieur du Mekong

Résumé

On décrit les techniques traditionnelles de pisciculture en cages et l'adaptation de ces techniques dans la partie méridionale du Viet Nam.

Au Kampuchea, les cages sont faites de tiges et d'écailles de bambou, fréquemment renforcées de planches et de poutres de bois. Les dimensions des cages varient entre 40 et 625 m^3 et l'on élève notamment des *Pangasius*, des *Clarias*, des *Channa*, et des *Oxyeleotris*. Les alevins destinés à la mise en culture sont prélevés dans la nature, et les poissons sont nourris de produits animaux ou végétaux locaux. D'après une enquête réalisée en 1969, 946 cages fonctionnaient au Kampuchea.

La pisciculture en cages a été entreprise dans la partie méridionale du Viet Nam par des immigrés du Kampuchea et la technique prend rapidement de l'extension auprès des pêcheurs et entrepreneurs du pays. On estime actuellement à 10 000 le nombre de cages fonctionnant dans la partie méridionale du Viet Nam. Les dimensions des cages varient entre 60 et 181 m^3 et peuvent durer approximativement dix ans. Parmi les principaux genres élevés on citera *Barbus* et *Leptobarbus* (dans 61% des cages), *Pangasius* (20%) et *Channa* (18%). On recueille les alevins dans la nature avec des barrages, des nasses, des sennes coulissantes et des carrelets. On les stocke à des densités qui varient entre 80 et 361 alevins/m^3. Les poissons sont nourris de produits animaux et végétaux locaux et l'indice moyen de conversion alimentaire est de 4,0. L'élevage s'étend sur 9 à 11,5 mois, suivant l'espèce et l'on estime entre US$ 2 500 et US$ 31 500 la valeur de la récolte, soit 3 000 à 25 000 kg/cage/an. Les frais de fonctionnement de la pisciculture en cages dans la partie méridionale du Viet Nam oscillent entre 120 et plus de 300% des investissements en capital, pour un bénéfice net rapporté au coût total de l'ordre de 12 à 44%.

La pisciculture en cages n'est pas affectée par les nombreux problèmes de la pisciculture en étangs et l'on recommande de chercher à élaborer des pratiques culturales rationnelles en cages.

Cultivo de peces en jaulas flotantes en la cuenca baja del río Mekong

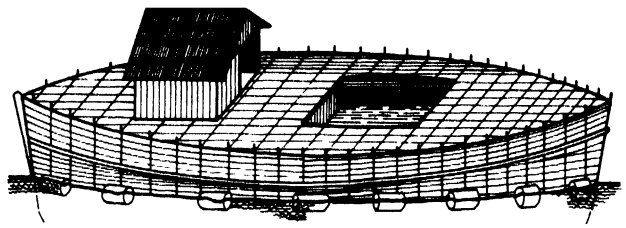
Extracto

Se describen las técnicas tradicionales de cultivo en jaulas en Kampuchea y las adaptaciones de esas técnicas utilizadas en el sur de Viet Nam.

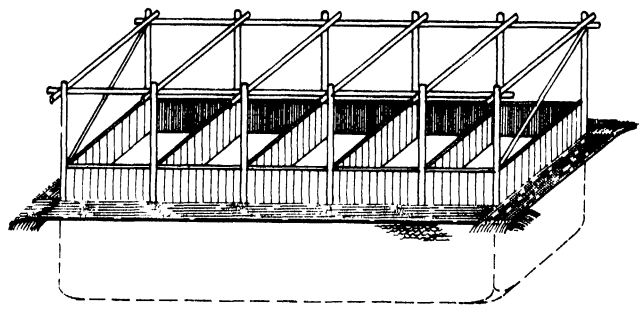
En Kampuchea las jaulas se construyen con varas y tablillas de bambú, reforzadas con frecuencia con travesaños y vigas de madera. Las dimensiones de las jaulas varían de 40 a 625 m^3, y los principales géneros cultivados son *Pangasius*, *Clarias*, *Channa* y *Oxyeleotris*. Los jaramugos utilizados para la cría son de procedencia natural. Se alimenta a los peces con productos vegetales o animales disponibles localmente. Según una encuesta hecha en 1969, funcionaban entonces en Kampuchea 946 jaulas.

El cultivo en jaulas fue introducido en el sur de Viet Nam por inmigrantes de Kampuchea, pero esta técnica está adquiriendo rápidamente popularidad entre los pescadores y piscicultores del sur de Viet Nam. Se calcula que actualmente existen en el sur de Viet Nam 10 000 jaulas de este tipo. Las dimensiones de las jaulas varían de 60 a 181 m^3, y su vida media es de diez años. Los géneros cultivados más importantes son *Barbus* y *Leptobarbus* (en el 61% de las jaulas), *Pangasius* (20%), y *Channa* (18%). Los jaramugos se capturan en cursos naturales de agua con alambradas, trampas, chinchorros y salabardos, y se colocan en las jaulas a razón de 80 a 361 jaramugos/m^3. Se alimenta a los peces con productos vegetales y animales disponibles localmente. El índice medio de conversión de alimentos es de 4,0. El período de cultivo oscila entre 9 y 11,5 meses, según la especie, y se obtienen rendimientos de 3 000–25 000 kg/jaula/año, por un valor de US$ 2 500 a 31 500. Los gastos de funcionamiento de las jaulas en el sur de Viet Nam son superiores de 120 a 300% a las inversiones de capital, mientras los beneficios netos representan en general del 12 al 44% de los gastos totales.

El cultivo en jaulas no está expuesto a los muchos problemas propios del cultivo en estanques y se recomienda que se preste mayor atención al desarrollo de buenos sistemas de cultivo en jaulas.



a. A boat-shaped cage



b. A battery of small cages

Fig 1. Design of floating fish cages used in Kampuchea

1 Introduction

Floating-cage culture of fish is an age-old practice which perhaps originated in Kampuchea in the Lower Mekong Basin. It is common practice in the Great Lake area of Kampuchea to hold commercially valuable live fish in bamboo cages until they can be transported to markets in the capital city of Phnom Penh. Species generally held in this fashion are predatory fish with low-oxygen requirements, like murrels (snakeheads), some catfish and the sand goby. The bamboo cages are either trailed in water behind a fishing boat or form a part of the boat through which water can flow freely. As transportation to distant markets and the exigencies of fishing involve impounding the fish for protracted periods, fish held in these cages are fed on small trash fish and refuse from the fisherman's kitchen. The impounded fish grow rapidly on this food and increase considerably in market value. This typically Kampuchean mode of fish-holding, transportation and marketing probably evolved into floating cage culture which is now widely practised both in Kampuchea and Viet Nam.

This paper describes (briefly) the traditional practice of cage culture as it is practised in Kampuchea and (in more detail) as adapted in Viet Nam. Information presented here is derived from the author's observations and the results of several fishery surveys conducted for the UN Committee for Coordination of Investigations of the Lower Mekong Basin (Mekong Committee). This subject is considered to be of topical interest to aquaculturists in view of the efforts now being made in different parts of the world to develop and expand cage culture of fish.

2 Traditional cage culture in Kampuchea

Bamboo poles and splints are the basic materials used to construct fish cages in Kampuchea. Large cages are often reinforced with wooden planks and beams. Generally, cages trailed behind boats or those moored near shore are box-shaped, while cages that form part of a fisherman's boat are streamlined to fit the shape of the boat (Fig. 1a). Cages vary considerably in size with large cages being 4–5 m wide, 40–50 m long and 2·5–3·0 m high with a submerged portion of 2·0–2·5 m. Small cages average 4 m wide, 4 m long and 2·5 m high. Often, a large number of small cages are lashed together to form a block measuring some 80 m long and 4 m wide (Fig. 1b). These blocks are provided with running boards made of wooden planks or bamboo poles to facilitate feeding, stocking and harvesting. The cages are buoyed with large, airtight metal drums.

Fishes cultured are mainly catfish of the genera *Pangasius* and *Clarias*, murrels (or snakeheads) of the genus *Channa* and the sand goby, *Oxyeleotris marmorata*. Occasionally, the cyprinids *Cyclocheilichthys* and *Puntius* are also cultured. Fry for stocking in cages are obtained from natural sources. The number stocked in each cage depends on the species cultured, size of the cage, and the practice of the owner. A large cage, as described earlier, is stocked with between 6 000 and 10 000 fry, generally during the months June to August. Fry and fingerlings are fed on cooked pumpkin, banana and a combination of cooked, broken, glutinous rice and rice bran. As the fish grow in size they are fed on pieces of raw fish, small live fish and kitchen refuse. Generally, monoculture is practised, though sometimes cyprinids are stocked in conjunction with murrels and the sand goby in a predator/prey culture operation. Stocks are harvested during February–May by which time the fish have grown to 1·5–2·5 kg each.

Fish cultured in cages are sometimes afflicted by parasites and fungal diseases. The indigenous curative measure is to dump cow dung and the bark of certain trees, or a mixture of salt, mud and leaves into the cage. The efficacy of these measures has not been systematically evaluated.

According to a survey conducted for the Mekong Committee in 1969, a total of 946 cages were operating in Kampuchea. Of these, 723 were located in the Mekong itself and the rest in the Great Lake/Tonle Sap sector (Overseas Technical Cooperation Agency, 1969). Cage culture is generally considered a lucrative practice here.

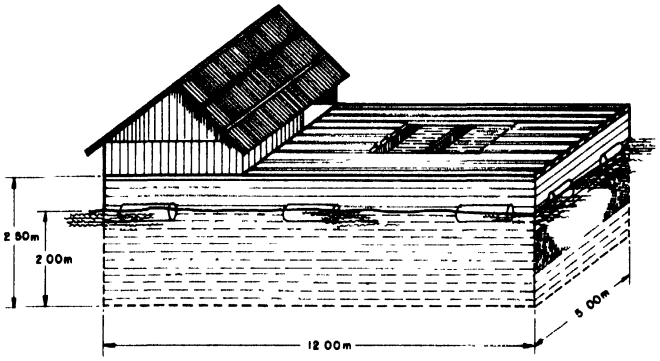


Fig 2. Design of a typical fish cage used in southern Viet Nam

However, accurate economic data were unavailable to the survey in view of the fisherman's fear of taxation.

3 Cage culture of fish in southern Viet Nam

Cage culture is of recent origin in the southern part of Viet Nam where it is practised mostly by immigrants from Kampuchea who have floated their cages down the Mekong River across the border. Some Vietnamese fishermen and entrepreneurs who have learnt the technique, either by observation or by instruction, have also taken to cage culture in the last three years. Chou Doc and Kien Phong provinces, which are adjacent to Kampuchea, are the main centres of cage culture in southern Viet Nam. Other provinces where cage culture is practised on a limited scale are An Giang and Phnong Dinh. Official figures based on local census records indicate that there are 7 000 cages of different sizes in Chou Doc province, which has by far the largest number of cages. The total number of cages in operation in southern Viet Nam is estimated to be in the region of 10 000.

3.1 *The cages*

The cages used here are box-shaped devices constructed of closely adjoining thick planks of hardwood. On the central section of the submerged portion of the two shorter sides of the cage, wire-gauze screened panels are affixed to permit free flow of water through the cage (Fig. 2). The panels are usually protected from floating logs and other objects by strong metal grills. Dwellings where the fisherman–owner usually lives cover about a third of the upper deck. The rest of the deck is left open and the planks are so arranged as to leave 2–3 inch spaces between them. The upper deck has, in addition, large panels which can be easily lifted off to provide access to the interior of the cage so that fish can be harvested. Three or four manhole-type openings on the deck facilitate fish feeding and observation.

Although cages vary in size, they can be broadly categorized as small or large cages. Small cages measuring 1·5 m × 2·0 m × 1·5 m (depth) are often used for rearing fry to fingerling or early juvenile stages for stocking in large cages. The dimensions of large cages fluctuate around 5 m × 12 m × 2·5 m (depth); these are used for rearing fish to marketable sizes. The volume of an individual cage, as observed in a sample of 25 cages, ranges between 60 and 181·3 m^3 (average 126 m^3). The cages are secured directly to shore or moored near shore in rivers and their tributaries (Fig. 3). They are buoyed by airtight metal drums. While in



Fish cage-village association.



Single cage anchored offshore.



Fish feed and feeding area.



Examining stock.

Fig 3. Typical cage fish culture in southern Viet Nam

use, all but the upper 0·5 m of the cage is submerged. Depending on the quality of material used and care and maintenance bestowed, the life of a cage varies between 6 and 15 years and averages 10 years. Generally, the first three years are repair-free; therefore, repair and maintenance costs increase progressively. Some cage owners raise their cages out of water every year at the end of each fish culture season to allow the wood to dry and to replace the screened side panels—a practice believed to increase the life of the cage.

3.2 *Species*

Species commonly cultured in cages are: (*i*) Murrels—*Channa micropeltes* and *C. striatus*. (*ii*) Pangas—*Pangasius larnaudei* and *Pangasius* spp. (*iii*) Barbs—*Barbus altus* and *Leptobarbus hoeveni*. (*iv*) Common Carp—*Cyprinus carpio*.

The aim of the fish culturist is to practise monoculture of a selected species. However, when fry of desired species are not available in required numbers, the shortage is made up by stocking cages with readily available fry of any species. A recent Mekong survey of 173 cages (Rainboth *et al*, 1974) has shown that barbs are cultured in 61% of the cages, pangas in 20%, murrels in 18% and miscellaneous species in 1%.

3.3 *Stocking*

Cages are stocked with 38–63 mm (1·5–2·5 inches) fry of the desired species, usually during August to October. Some cage owners, however, prefer to stock fingerlings or even early juveniles. Fry are obtained from natural sources, such as rivers, canals and paddy fields, with weirs, traps, seines and dip nets. Fry are either sold directly to cage owners or to wholesalers who raise the fry further in small cages to fingerling or early juvenile sizes. Although stocking large cages directly with fry is initially less expensive, the wide disparity in size of the fry obtained from fishermen has an adverse effect on the total production of fish in the cage. Wholesalers generally grade their stock and sell fingerlings or early juveniles in lots of uniform sizes. Uniformity in size of initial stocking material is generally conducive to increased production in cages. Stocking density of fish fry in cages varies with the species. An analysis of random samples of cages (Table I) has indicated that stocking density for murrels is about 80 fry/m^3, for pangas 93 fry/m^3, for barbs 361 fry/m^3 (Rainboth *et al*, 1974) and for common carp 107 fry/m^3.

3.4 *Feeds*

Feeds used in cage culture depend on the species cultured. Predatory fish like murrels, are fed on forage fish. Supplies of forage fish from natural sources are irregular and their price is high. Culture of forage fish as feed is considered by the fishermen to be uneconomical and technically unfeasible. Culture of predatory murrels is, therefore, practised only by rich entrepreneurs with alternative sources of income. *Pangasius* spp. are fed on vegetable matter, such as chopped leaves, rice bran, cattle manure, and forage fish when available. In addition, food for murrels and pangas is supplemented with cooked or uncooked flesh of miscellaneous organisms, principally mussels and snails collected by the fisherman. Barbs are usually fed on chopped greens, wine mash, rice bran, corn chaff, lotus seeds, starchy roots, squash and bat guano.

Feed quantities and schedules are not regulated but depend mainly on the availability of feed, the fisherman's capacity to purchase it and his judgement of satiation level. Feed is chosen on the basis of its cost and ready availability rather than on its nutritive value and growth-enhancing potential. Therefore, food conversion rates obtained are not favourable and fluctuate around 4·0. One exception, however, was an instance where the common carp was cultured in an experiment monitored by staff of the Mekong Committee. The fish were fed on a mixture of rice bran, fish meal, and soya bean cake. With this feed, the conversion rate obtained was 1·8.

3.5 *Production*

Harvesting usually takes place during March to August, after a culture period ranging from 9 to 11·5 months (see Table I) depending on species cultured. Maximum production per unit area appears to be achieved in the case of the common carp, followed by murrels, pangas and barbs in that order (see Table I). Some cage owners delay harvesting to ensure a higher market price. The size of the harvest usually ranges from 3 000 to 25 000 kg/cage/year depending on various factors, principal among these being the species raised and the quality and quantity of feed administered.

3.6 *Economics*

Cage culture of fish is generally considered to be a very lucrative practice. For this reason, the number of cages operated has been increasing very rapidly in recent years, particularly near urban centres. Annual income from a cage varies generally from US$ 2 500 to US$ 31 500.

Fish food is the major operating cost in cage culture operations. Operating costs exceed capital investment costs by 120 to over 300%. Net returns on total costs generally range between 12 and 44%. However, in an exceptional

TABLE I
SUMMARY OF OBSERVATIONS ON CAGE CULTURE IN VIET NAM

Species	*Number of cages observed*	*Average volume of cage (m^3)*	*Stocking density (fry/m^3)*[a]	*Average culture period (months)*	*Average production for culture period (kg/m^3)*	*Calculated average production/12 months (kg/m^3)*
Barbs—*Leptobarbus hoeveni* and *Barbus altus*	15	122·0	361·3	11·2	42·5	45·5
Pangas—*Pangasius larnaudei* and *Pangasius* spp.	5	116·7	93·2	10·2	53·1	62·1
Murrels—*Channa micropeltes* and *C. striatus*	4	154·8	79·5	9·0	84·5	112·8
Common carp—*Cyprinus carpio*	1	187·5	106·7	11·5	122·2	133·3

[a] Fry—range in length 38–63 mm (1·5–2·5 inches)

TABLE II
COSTS AND INCOMES IN CAGE CULTURE IN VIET NAM

	Range	*A cage in Chou Doc*	*A cage in Bien Hoa*
A. *Annual Costs* (US$)[a]			
I. *Capital Costs*			
(a) Cage construction	581–3 306	2 397	2 314
(b) Accessories[b]	150–6 612	661	826
II. *Recurring*			
(a) Fry[c]	413–2 479	1 322	1 653
(b) Feed	653–8 264	8 225	5 633
(c) Labour	331– 826	496	661
(d) Repairs and maintenance[d]	83– 331	132	[e]
Total	2211–21 818	13 233	11 107
B. *Annual Income* (US$)			
(a) Value of fish produced	2 479–31 500	17 136	31 500

[a] Converted at the rate of VN. Ptrs. 605 = US$ 1.00
[b] Boats, motors, pumps, food choppers, grinders, *etc.*
[c] 38–63 mm (1·5–2·5 inches) long
[d] No expenditure on this item for the first three years
[e] This cage was only one year old—hence no expenditure on this item

instance of common carp culture, the net return over total investment was 183% as a result of high production coupled with the prevailing high market price of fish. Benefit/cost ratios (Pantulu, 1974) at 15% discount rate for the two cage-culture operations shown in Table II, are estimated to be 1·61 for an enterprise in Chou Doc and 3·67 for one in Bien Hoa.

Despite the profitability of cage culture, the high capital and high recurring costs involved make it necessary for the fishermen to seek loans. At the time the survey was conducted in 1974, bank loans were difficult to obtain, particularly for the cage-owning fisherman who was considered a poor financial risk. Relatively rich entrepreneurs could easily obtain loans at favourable rates of interest. Interest rates fluctuated between 12 and 30%, depending on the source and the size of the loan.

3.7 *Sociological aspects*

It is reported that 70% of the cage owners in southern Viet Nam are migrants from Kampuchea and the rest are relatively more affluent local entrepreneurs (van Heck, 1974). The immigrant cage owners tend to live together in floating villages of their own (see Fig. 3). Each fisherman generally owns one cage and has the role of an owner-cum-operator, living with his family in a dwelling built over his cage. Some absentee urban owners who have other occupations own more than one cage, the maximum number owned being ten. These absentee owners employ hired hands to live and work on their cages. After installation of his cage, the operator prepares the feeds and feeds the fish. The more enterprising owners fish for or collect feed items, such as small fish, molluscs, and plants, as well as fry for stocking. The harvest from the cages is usually purchased at site by merchants in carrier boats.

Some of the more significant constraints to the development of cage culture in southern Viet Nam were the lack of loan facilities at reasonable interest rates, insufficient supply of fingerlings of desired species for stocking, inadequate supply of effective fish feeds, and increasing pollution of rivers by industrial and agricultural effluents.

4 Conclusion

Cage culture can be considered to represent an advanced type of aquaculture; its productivity is 10–20 times higher than that of pond culture for comparable inputs and area. Cage culture also eliminates the drawbacks inherent in pond culture, such as loss of stock due to flooding, seepage and evaporation losses and the resultant need for water replacement, problems of pond excavation in marshy and waterlogged areas, dependence on soil characteristics which are not always favourable, and the inescapable proximity to agricultural areas and chances of contamination of ponds by agricultural chemicals. Fish cages can be located conveniently in waterways and water areas near urban market centres, ensuring supply of fresh fish without expensive preservation and transportation.

Another factor limiting fish farming in ponds is the increasing demand on land for agricultural, industrial and habitational uses which are likely to make suitable land unavailable for aquaculture and even encroach on existing pond sites and operations. The increasingly rapid adoption of modern techniques of intensive agriculture and the concomitant hazard of contamination of aquaculture operations by agricultural chemicals is more immediate in the case of pond culture than in cage culture. In view of this, it is perhaps reasonable to consider cage culture as one of the important aquaculture practices that will prevail in the future. Research institutions and organizations charged with developing aquaculture might, therefore, devote more attention to the development of cage culture. It is suggested that agencies responsible for the development of aquaculture consider establishing cage culture experiment stations in different regions with a view to developing scientifically sound culture practices.

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A Review of Cage Fish Culture and its Application in Africa

A. G. Coche

Abstract

Cage culture of fish, which originated in the Far East and was introduced into the USA and Europe, has had virtually no practical application in Africa. Cage culture of fish has numerous advantages over other culture techniques but there are some serious limitations which must be taken into consideration before it is applied on a large scale.

The most commonly reared species in cages include: (*i*) in fresh water—*Cyprinus carpio, Pangasius* spp., *Silurus glanis, Clarias* spp., *Ictalurus punctatus* and *Ophiocephalus* spp., and (*ii*) in brackish water—*Seriola quinqueradiata, Salmo* spp. and *Oncorhynchus* spp. *Tilapia nilotica* has also been reared experimentally in cages in freshwater ponds.

The types of cages used for fish culture can be classified into: (*i*) surface cages resting on the bottom, thus occupying the full water column; (*ii*) cages floating at the surface; (*iii*) cages submerged, either floating in mid-water or resting on the bottom. Ideally, cages have to be inexpensive, durable and easy to handle. These criteria are met in different ways depending on the materials available locally, on the type of culture undertaken and on the possible investments which may be made according to local economic conditions.

Artificial feeds used in cage culture vary from raw materials obtained locally to nutritionally-balanced pelleted feeds. While most of the feeding is by hand, the use of mechanized feeders is increasing.

Fastest growth rate in freshwater cage culture has been recorded for *Cyprinus carpio*, which grow from 40–80 g to 400 g in about four months and can reach 800 g in 6–8 months. Growth of *Ictalurus punctatus* is also good (700 g in 7–8 months), while *Salmo gairdneri* has slow growth rate (100 g in four months). *Tilapia nilotica* appears to have intermediate growth rate, as the average growth during experiments in Lake Kossou, Ivory Coast, was 120–200 g.

The initial stocking rate of fish in intensive cage culture varies according to the species, generally between 15 and 25 kg/m^3, but the total production of cages increases as the initial biomass increases. The average maximum production per month for the principal fish species studied is summarized as follows: (*i*) *C. carpio*—35+kg/m^3/month (when reared for 3·5 months); (*ii*) *I. punctatus*— 20 kg/m^3/month (9 months); (*iii*) *T. nilotica*—17 kg/m^3/month (4 months); and (*iv*) *S. gairdneri*—15+kg/m^3/month (4 months).

In considering the costs involved in various cage culture activities, feeding costs were highest (60%), followed by labour (13·5%), facilities (8·0%), operational costs (7·5%), and seed stock (6·5%).

It is concluded that the basic technology for the design and construction of cages appears to exist, and the difficulty in developing cage culture in new areas lies in adapting the technology to local conditions.

Revue de la pisciculture en cages et de ses applications en Afrique

Résumé

La pisciculture en cages, qui a été réalisée en premier lieu en Extrême-Orient puis aux Etats Unis et en Europe, n'a jamais été pratiquée en Afrique. Elle offre de nombreux avantages par rapport aux autres techniques encore qu'elle connaisse certaines limitations importantes dont il faut tenir compte avant de la pratiquer à large échelle.

Les espèces les plus fréquemment élevées en cages sont notamment: (*i*) en eau douce—*Cyprinus carpio, Pangasius* spp., *Silurus glanis, Clarias* spp., *Ictalurus punctatus* et *Ophiocephalus* spp.; et (*ii*) en eaux saumâtres—*Seriola quinqueradiata, Salmo* spp., et *Oncorhynchus* spp. On a également pratiqué l'élevage expérimental en cages de *Tilapia nilotica* dans des étangs d'eau douce.

Les cages employées en pisciculture sont de plusieurs types: (*i*) cages émergentes reposant sur le fond occupant ainsi toute la colonne d'eau; (*ii*) cages flottant à la surface; ou (*iii*) cages submergées, flottant entre deux eaux ou reposant sur le fond. L'idéal serait que les cages soient peu onéreuses, durables et d'un maniement facile. Ces conditions sont réalisées de différentes façons dans le monde suivant les matériaux disponibles sur place, le type d'élevage entrepris et les investissements possibles compte tenu des conditions économiques locales.

La nourriture artificielle employée dans la pisciculture en cages varie. On utilise des matières premières obtenues sur place aussi bien que des granulés équilibrés du point de vue nutritionnel. Le nourrissement s'effectue le plus souvent à la main, mais l'utilisation de systèmes mécanisés se généralise.

On a enregistré les taux de croissance les plus rapides en eau douce pour *Cyprinus carpio*, qui passe de 40–80 g à 400 g en 4 mois environ et peut atteindre 800 g en 6–8 mois. La croissance de *Ictalurus punctatus* est également bonne (700 g en 7–8 mois), tandis que *Salmo gairdneri* ne se développe que lentement (100 g en 4 mois). *Tilapia nilotica* a un taux de croissance intermédiaire; en effet, au cours d'expériences réalisées dans le lac de Kossou (Côte-d'Ivoire), ce taux a été de 120 à 200 g.

Dans la pisciculture en cages, le taux d'empoissonnement initial varie suivant l'espèce; il est généralement de l'ordre de 15 à 25 kg/m^3. Cependant, la production totale des cages augmente à mesure de l'accroissement de la biomasse originelle. La production mensuelle maximale moyenne s'établit comme suit pour les principales espèces examinées: (*i*) *C. carpio*—35+kg/m^3/mois et davantage (pour une durée d'élevage atteignant 3,5 mois); (*ii*) *I. punctatus*—20 kg/m^3/mois (9 mois); (*iii*) *T. nilotica*—17 kg/m^3/mois (4 mois); et (*iv*) *S. gairdneri*—15+kg/m^3/mois et davantage (4 mois).

Pour ce qui est du coût des différentes activités de pisciculture en cages, on a déterminé que les frais d'alimentation représentaient la plus grosse partie (60%), suivis de la main-d'oeuvre (13,5%), des installations (8,0%), des frais de fonctionnement (7,5%) et du stock d'alevinage (6,5%).

On en conclut que les techniques de base relatives à la conception et la construction des cages sont disponibles et que les progrès de la pisciculture en cages ne sont freinés que par les difficultés d'adaptation des techniques à la situation des nouvelles zones.

Examen de la piscicultura en jaulas y su aplicación en Africa

Extracto

La piscicultura en jaulas, que comenzó en el Lejano Oriente y pasó luego a los Estados Unidos y a Europa, no ha tenido virtualmente ninguna aplicación práctica en Africa. El cultivo de peces en jaulas tiene varias ventajas respecto a otras técnicas de cultivo, pero hay también algunas graves limitaciones que hay que considerar antes de aplicarlo a gran escala.

Entre las especies más comúnmente criadas en jaulas figuran: (*i*) en aguas dulces—*Cyprinus carpio, Pangasius* spp., *Silurus glanis, Clarias* spp., *Ictalurus punctatus* y *Ophiocephalus* spp.; y (*ii*) en aguas salobres- *Seriola quinqueradiata, Salmo* spp.; *Oncorhynchus* spp. También se ha criado experimentalmente en jaulas, en estanques de agua dulce, *Tilapia nilotica.*

Los tipos de jaulas utilizados en piscicultura pueden clasificarse en tres grupos: (*i*) jaulas que emergen en la superficie y descansan sobre el fondo, ocupando, por tanto, toda la columna de agua; (*ii*) jaulas flotantes en la superficie; o (*iii*) jaulas sumergidas, bien flotando an media agua o descansando sobre el fondo. Lo ideal es que las jaulas sean poco costosas, duraderas y fáciles de manipular. Estos criterios se atienden en diversas formas en distintas partes del mundo, según los materiales de que se dispone localmente, el tipo de cultivo de que se trata y las inversiones que son posibles de acuerdo con las condiciones económicas locales

Los piensos artificiales utilizados para la piscicultura en jaulas varían desde materias primas obtenidas localmente hasta piensos granulados bien equilibrados desde el punto de vista nutricional. La mayor parte de la alimentación se hace a mano, pero va en aumento el empleo de alimentadores mecánicos.

La tasa más rápida de crecimiento en el cultivo en jaulas en agua dulce se ha conseguido con *Cyprinus carpio* que crece de 40–80 g a 400 g en unos cuatro meses y puede alcanzar 800 g en 6–8 meses. También el crecimiento de *Ictalurus punctatus* es bueno (700 g en 7–8 meses), mientras el ritmo de crecimiento de *Salmo gairdneri* es lento (100 g en 4 meses). La tasa de crecimiento de *Tilapia nilotica* es media: el crecimiento promedio registrado en experimentos en el Lago Kossou, en la Costa de Marfil, fue de 120–200 g.

La tasa inicial de siembra de peces en el cultivo intensivo en jaulas varía según la especie, generalmente entre 15 y 25 kg/m^3, y la producción total de las jaulas aumenta a medida que aumenta la biomasa inicial. La producción media máxima por mes de las principales especies de peces estudiadas ha sido la siguiente: (*i*) *C. carpio*— 35+kg/m^3/mes (criadas durante 3,5 meses); (*ii*) *I. punctatus*—20 kg/m^3/mes (9 meses); (*iii*) *T. nilotica*—17 kg/m^3/mes (4 meses); y (*iv*) *S. gairdneri*—15+kg/m^3/mes (4 meses).

Por lo que se refiere a los costos necesarios para el cultivo en jaulas, estos se desglosan, a saber, los piensos (60%), seguido por la mano de obra (13,5%), las instalaciones (8,0%) los gastos de funcionamiento (7,5%) y los peces para semilla (6,5%).

Se concluye que existe la tecnología básica necesaria para el diseño y construcción de jaulas y que la dificultad para introducir el cultivo en jaulas en nuevas zonas consiste en adaptar la tecnología a las condiciones locales.

1 Introduction

Cage culture of fish consists of raising fish from the juvenile stage to commercial size in a volume of water enclosed on all sides, including the bottom, while permitting the free circulation of water through the 'cage'.

Even though this method of fish culture which originated in the Far East has rapidly developed during the last decade, in the United States and Europe, until lately it has had practically no application in Africa. However, research

on cage culture has recently been started. The Kossou hydroelectric dam in the centre of the Ivory Coast has resulted in the inundation of a vast region, the loss of plantations (coffee and cacao), and the displacement of about 70 000 people. The subsequent increase in population density around the new lake and the lack of fertile land has required diversification of the regional economy and intensification of the methods of production. Development of the fishing industry has been officially encouraged and thus the first experiments of rearing fish in cages were started in January 1974 (Coche, 1975, 1977).

This review was made to define the inherent problems of cage culture with special reference to Africa. It is based on a study of world literature on the subject as well as personal experience in Africa.

2 Advantages and limitations of cage fish culture

The advantages and limitations of rearing fish in cages are presented in Table I based primarily on Trotter (1970) and Lee (1973).

The advantages are numerous, especially if one considers that this method of production can be used in most water bodies without any special arrangements. In water-filled excavations (*eg*, old quarries and mines), irrigation canals, evacuation canals of power plants (heated effluents, for example), and in undrainable ponds encumbered by tree stumps or invaded by undesirable fish species, cage fish culture is probably the only practical and economically feasible method for fish production. This method can equally be applied to other aquatic environments such as rivers, lakes, lagoons, estuaries and coastal bays. It is highly flexible in its application and is perfectly adaptable to production and commercialization.

In industrialized countries, cage culture of salmonids in the littoral marine zone has helped remedy the growing lack of fresh running water of good quality available on land (Milne, 1972). For the intensive production of fish species whose culture requires a saline environment, cages appear to be the most economical method (Landless, 1974). Norway, for example, faced with increased organic pollution and rising costs of pumped water, now tends to use floating cages in preference to ponds and enclosures (Brett, 1974). In fact, for mariculture, cage culture is today considered an important technological breakthrough.

Cage culture also permits more intensive use of existing inland waters. In particular, this method is progressively expanding in the heated effluents of power plants where very high fish production can be obtained even in temperate countries (Anon., 1974a; Collins R. A., 1970; FAO, 1974; Gribanov *et al*, 1968; Heald, 1973; Steffens, 1969, 1970; Huisman, personal communication). In Africa, the creation of large man-made lakes can be used to a similar end, although the inherent problems of this cultural method will first have to be solved through research (Coche, 1975; UNDP/FAO, 1975). Similarly, intensive exploitation of the numerous coastal lagoons in West Africa and in the Mahgreb could be accomplished by rearing fish in cages. Numerous possibilities for its application in African rivers also exist (*eg*, UNDP/FAO, 1975; FAO, 1975a).

However, there are some serious limitations (Table I) that must be taken into consideration and solved locally before large-scale development of cage fish culture. A regular and reliable source of fingerlings and feeds should be assured. Competent extension services should be available.

Without doubt, cage fish culture offers great possibilities in Africa. But there are still numerous technical difficulties. For their solution, a strong research effort appears indispensable.

3 Present status of cage fish culture

The concept of raising fish in cages is far from new. This method was described for the first time by Lafont and Saveun in 1951 as cited by Hickling (1962). It has been traditionally used for about a century in Kampuchea and is widely practised along the Tonle Sap, the Mekong River and their tributaries for the production of fish, mainly

TABLE I
ADVANTAGES AND LIMITATIONS OF CAGE FISH CULTURE

Advantages	*Limitations*
1. Possibility of making maximum use of all available water resources	Difficult to apply when the water surface is very rough
2. Economic use of water	
3. Helps reduce pressure on land resources	
4. Facilitates combination of several types of culture within one water body; treatments and harvests remaining independent	
5. Easy relocation of culture installations in case of emergency	
6.	Need for adequate water renewal in the cages for elimination of metabolites and maintenance of a high dissolved oxygen level. Sometimes rapid fouling of the cage walls requiring frequent cleaning
7. Optimum utilization of artificial food for growth, minimizing its conversion rate to fish flesh	High dependence on artificial feeding. High quality balanced food desirable; in particular proteins, vitamins and minerals. Feed losses possible through the cage walls
8. Easy daily observation of the fish population	
9. Easy control of fish reproduction (especially of *Tilapia* spp.)	
10. Easy control of competitors and predators	Sometimes important interference by the natural fish population round the cages (carps in particular)
11. Reduced fish handling and mortalities	Increased susceptibility of fish to a dissolved oxygen deficit
12. Parasite and disease control are easier and more economical (especially in floating cages)	
13. Fish harvest is easy and flexible	
14. Complete harvest of the fish production	
15. Harvest of a relatively uniform product	The risks of theft are increased
16. Storage and transport of live fish greatly facilitated	
17. Initial investment is relatively small	Period for amortization of the capital invested is relatively short
	Increased labour costs for handling, stocking, feeding and cage maintenance

Siluridae and Clariidae (Hickling, 1962; FAO, 1970; Huet, 1970).

Historically, this method of fish culture has progressively expanded to the other Far Eastern countries. It first spread to Thailand, where for some fifty years cages floating in running water have been used following the Kampuchean method (Ling, 1967; FAO, 1970; Bardach, Ryther and McLarney, 1972). Apparently this technique then appeared in the island of Java, Indonesia, where it was adopted around 1940 as originally described by Vaas and Sachlan in 1956 (cited by Hickling, 1962). Numerous bamboo cages standing along the shores or rivers (greatly enriched by town sewage) produced 200 g carps (*Cyprinus carpio*) in four months, without additional feeding (Huet, 1956; Hickling, 1962).

About ten years later Japan started experimenting with fish culture in floating cages made from netting material. *Seriola quinqueradiata* (yellowtail) in brackish water and *C. carpio* in lakes then proved to be excellent producers (Kuronuma, 1968; Furukawa, 1973; Ling, 1973). By 1970 the commercial production of fish had reached 52 000 tons (Anon., 1973a) from more than 9 000 floating cages covering less than 100 ha of water surface (Furukawa, 1973). The present number has been estimated at more than 15 000 net cages and the popularity of this method keeps increasing (Brett, 1974).

Following this success and combined with the development of balanced artificial feeds promoting intensive fish culture, the geographic distribution of cage culture has increased during the last decade. Introduced for the first time in 1964 into the US in Alabama (Trotter, 1970) active research is conducted today in at least ten states. Canada (Séguin, 1970), Chile (Arroyo, 1973), Finland (FAO, 1975b), UK (Milne, 1972) and the USSR (Gribanov *et al*, 1968; Anon., 1974a) are equally interested. Research is also being carried out in numerous other countries such as Hungary, Ireland, Norway, the Netherlands, Poland, the Federal Republic of Germany and the German Democratic Republic. Brett (1974), noting the excellent results obtained in Japanese and Norwegian brackish waters, has proposed that this new technology be applied to Canada. Recently cage farming has been started in the Philippines in Laguna de Bay (Milne, 1974).

Even though the commercial production of *Ictalurus punctatus* in cages in freshwater progresses fairly rapidly in the United States (Trotter, 1970; R. A. Collins, 1970 and 1970a; Bennett, 1971; C. M. Collins, 1972), the large commercial enterprises generally operate in brackish waters, in Japan (Milne, 1974), Australia and the UK (Milne, 1972; Glen, 1974), Norway (Bardach, Ryther and McLarney, 1972; Anon., 1973b; Brett, 1974) and in the Puget Sound, Washington, USA (Anon., 1973; Brett, 1974; Novotny, 1975). In the USSR the alternate intensive raising of carp and trout in heated effluents becomes increasingly popular (Anon., 1974a).

In Central Africa practically no experience in this field has been obtained before 1974. Some semi-intensive rearing was done in Tanzania in Lake Victoria using *Tilapia esculenta* and *T. zillii* (Ibrahim, Nozawa and Lema, 1975). In January 1974, a research programme was started in central Ivory Coast in the newly created Lake Kossou. It was based principally on the intensive production of commercial sized *T. nilotica* (Shehadeh, 1974; Coche, 1975, 1977). Research is actively pursued with the support of the Bandama Valley Authority (AVB) at its Kossou Fishery Development Centre. The possibilities for cage fish culture in Lake Kainji, Nigeria, as well as in the Niger River immediately below the Kainji dam, have been studied by FAO (UNDP/FAO, 1975).

4 Fish species raised in cages

In fresh water the fish species raised in cages essentially represent five families known for their hardiness: Cyprinidae (*C. carpio*), Siluridae (*Pangasius* spp. and *Silurus glanis*), Clariidae (*Clarias* spp.), Ictaluridae (*Ictalurus punctatus*) and Ophiocephalidae (*Ophiocephalus* spp.). Research has recently begun with Chinese carps in Hungary and the Netherlands in mono- and poly-culture. In brackish water only two families are largely represented: Carangidae (*Seriola quinqueradiata*) and Salmonidae (*Salmo* spp. and *Oncorhynchus* spp.). Several other species are experimentally cultivated in cages to determine their potential value. In fresh water, research is particularly concentrated on *Salmo gairdneri* and various *Tilapia* species. Among the latter, *T. aurea* has been experimentally raised in cages suspended in ponds at the Auburn University, Alabama, USA (Schmittou, 1969; FAO, 1969a, 1970b). This research has shown that this species presents an excellent potential for this type of culture. It has a rapid growth and a high survival rate. It easily accepts artificial pelleted feed, the conversion rate being favourable, and it easily adapts to relatively high population densities.

The qualities of *Tilapia* were confirmed during recent experiment carried out in Kossou with *T. nilotica*[1] (Coche, 1974, 1975, 1977). Its adaptability appeared to be similar to that of *S. gairdneri* and *C. carpio*, and might be superior to *I. punctatus* (R. A. Collins, 1972).

One of the principal disadvantages of raising *Tilapia* in ponds is their reproduction rate. If uncontrolled it leads quickly to overpopulation and stunting. This tendency disappears in cages where these fishes appear to be unable to reproduce successfully. Although cage culture does not necessarily stop the reproduction of *Tilapia* it is very unlikely that the eggs, even if fertilized, will be able to develop with success in a floating cage populated with a very high density of fish. Ibrahim, Nozawa and Lema (1975) mention that *T. esculenta* and *T. zillii* reach maturity in these conditions but do not reproduce in spite of the low fish density present. Coche (1977) confirms these results[2].

Up to the present there has been very little experimentation with fish polyculture in cages. It would appear however, that it might have real advantages. In Hungary very encouraging results have been obtained by associating the common carp (65%) with *Hypophthalmichthys molitrix* (18%) and *Aristichthys nobilis* (18%). In 177 days of rearing, *C. carpio* grew from 110 g to 540 g in average weight, the two other species growing from 150 g to 360 g and from 17 g to 200 g respectively (Csávás, personal communication). In Puerto Rico, experiments were

[1] Recently considered as *Sarotherodon niloticus* (Trewavas, 1973) by various authors

[2] *T. mossambica* would have successfully reproduced in cages floating in Lake Atitlan, Guatemala (Bardach, Ryther and McLarney, 1972). On 17 September 1975, *T. nilotica* larvae were observed in the mouth of a few females reared in cages in Kossou (D. Campbell, personal communication)

recently started combining *Tilapia aurea* and *Ictalurus punctatus* (FAO, 1974a).

5 Cages for fish culture

Ideally cages used for fish culture should be inexpensive, durable and easy to handle. These criteria are met in different ways throughout the world depending on the materials available locally, on the type of culture undertaken and on possible investments which may be made according to local economic conditions.

5.1 *Types of cages*

Three principal types of rearing cages can be distinguished: (*i*) surface cages resting on the bottom, thus occupying the full water column; (*ii*) cages floating at the water surface; (*iii*) submerged cages either floating in mid-water or resting on the bottom.

This last type, essentially marine, will not be discussed further with reference to inland waters[1]. Both of the others present numerous variations in their construction (Dahm, 1975). In practice, rearing cages floating on the water surface are universally preferred except in shallow rivers as in Indonesia, for example, where cages rest on the bottom (Hickling, 1962). In effect, it is generally recommended that rearing cages should be not less than 2 m above the benthic sediments, principally to reduce the incidence of fish parasites and to avoid the bottom zones that are more susceptible to deoxygenation following, for example, the accumulation and oxidation of unutilized food.

5.2 *Construction materials*

In traditional culture the materials usually utilized are lattices of bamboo and wood, or planks (Kampuchea, Indonesia, Thailand).

In more intensive culture fish culturists prefer synthetic netting (*eg*, Japan) or a rigid metal or plastic meshed material (*eg*, USA). It would appear that in industrial-scale operations the use of wire mesh is becoming more and more favoured (Dahm, 1975). Even though this material requires rigid supports which increase the weight of the cage thus requiring more flotation, galvanized wire mesh (*i*) requires less cleaning than other materials (especially in brackish waters—Milne, 1972); (*ii*) is easier to clean *in situ* than netting; and (*iii*) is very resistant to corrosion if appropriately treated. On the other hand, polyamide netting (dederon, nylon, capron or perlon) is less expensive (particularly in Africa). It does not need vertical rigid supports and therefore requires little flotation. Moreover, it is very easy to handle. Plastic mesh combines the big advantages of light weight and durability, its price being intermediate between that of netting and metal mesh[2]. In the presence of a strong water current (above 20–30 cm/sec), a rigid construction appears to be preferable to the heavy anchors on the lower corners required by net cages (Dahm, 1975).

When a rigid frame is used its construction material is either wood or metal (aluminium or steel). The major disadvantage of wood is its weight, which increases as water is absorbed. But the use of this easily worked and assembled material, particularly in Africa, results in lower initial cost. In the US the cages preferred for commercial culture are made of steel (R. A. Collins, 1970)[3]. One particularly well designed model is described by Kelley (1973). It allows the harvest of more than 200 kg of fish with a mechanical lift.

In contrast, net cages do not require rigid frames, submerged bags being easily attached to a surface structure. This structure can be made either in wood or metal. In Asia wood or bamboo are preferred and experiments with these materials are now in progress at Lake Kossou, Ivory Coast (Fig. 1). But in the western hemisphere steel (or aluminium) predominates and recently the use of scaffolding tubes

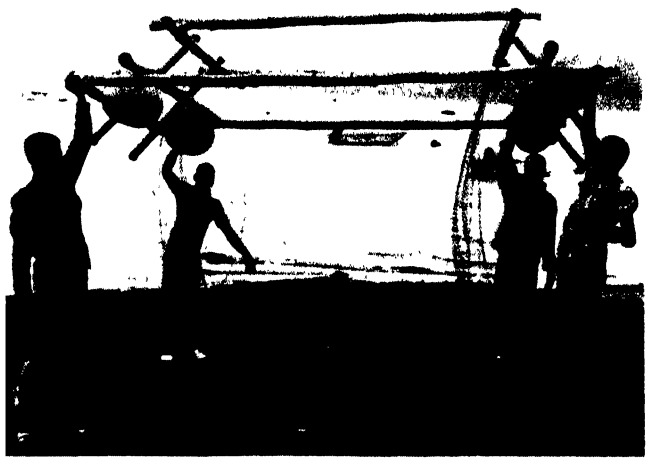


Fig 1. Net cage from Lake Kossou of 6 m³ capacity (2 × 2 × 1·5 m) with a surface structure of bamboo, flotation by four 30 l plastic drums, and with outside anti-predator net

and joints has been described by Landless (1974). A similar model was constructed in Lake Kossou in April 1975 for experimentation in African conditions (Fig. 2).

Hermann (1970 cited by Dahm, 1975) recommends the use of netting with twine of 210/18 (470 Rtex). The twine should preferably be dark coloured. If treated with tar it becomes very resistant and fouling is greatly reduced. Square rather than diamond-shape meshes are preferable

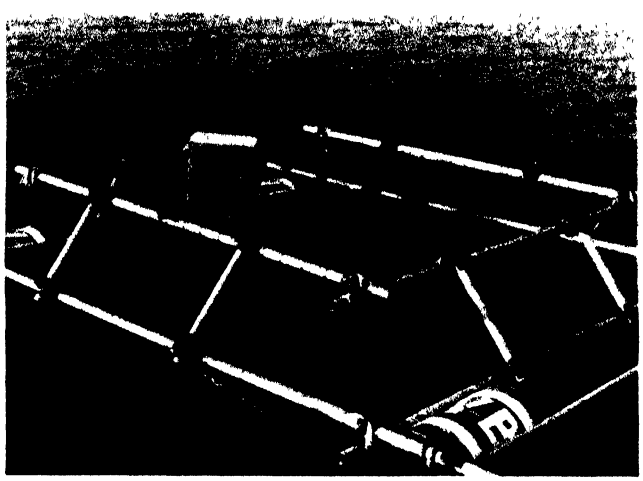


Fig 2. Net cage of 6 m³ capacity (2 × 2 × 1·5 m) with a surface structure of scaffolding steel pipe assembled with Mills joints (modified Landless 1974 model), floatation by four 60 l plastic drums, double net, and automatic pellet feeder

[1] Net cages (12 × 12 × 2·4 m) placed on the sea bottom in a depth of 10–15 m are being used in Scotland for the production of more than 2 tons of lobster with the assistance of divers (Milne, 1972)

[2] In Africa plastic mesh must still be imported, which considerably increases its price

[3] This author has designed a cage model made of welded metal mesh without a rigid frame (personal communication)

(Dahm, 1975). Knotless netting, which is more economical, has demonstrated an overall superiority, at least in brackish water (Novotny, 1975).

5.3 *Other cage components*

Three possible components annexed to cages for fish culture will be separately considered:

(*i*) *The flotation system*: The flotation of cages at the water surface can be accomplished in different ways using, for example, metal or plastic drums, sealed PVC tubing or stryofoam floats. Milne (1972) and Dahm (1975) present the different solutions adopted which can be classified into the four following categories: (*a*) single floats, without a surface structure (net cage); (*b*) surface structure with floating elements (net cage); (*c*) self-floating surface structure (net cage); (*d*) rigid underwater structure with floating elements (cage made from a stiff mesh such as plastic or wire).

Kelley (1973) proposes blocks of styrofoam protected against birds by thin aluminium foil and attached along two sides of the metal cage. A similar kind of flotation has been used with success in Lake Kossou (Fig. 3). Landless (1974) prefers reinforced concrete pontoons injected with styrofoam. For a similar cage model, but of reduced dimensions, four plastic drums provide adequate flotation (Fig. 2).

(*ii*) *The top covering*: The presence of an opaque top cover (Fig. 3) presents several advantages. It reduces the algal growth on the cage walls, stops predation, reduces the risks of theft, and sometimes encourages the fish to feed better. This last point, apparently critical for *I. punctatus* (Schmittou, 1969) is of much less importance for *S. gairdneri* (R. A. Collins, 1972). A top covering made from a fishing net (as in Japan, for example) might then be sufficient to stop bird predation.

(*iii*) *The feeding box (or ring)*: The need for a feeding box (Fig. 3) which holds the food and also decreases its loss, is somewhat controversial. Extended to the whole surface of the cage it contributes little, only limiting the dispersion of food by the fish. If only partial, it favours more aggressive individuals to the detriment of others. A feeding ring measuring 25 × 45 cm did not prove satisfactory in the culture of *I. punctatus* larger than 340–450 g (C. M. Collins, 1972). For *S. gairdneri* a partial feeding ring is not recommended (R. A. Collins, 1972). It appears to be much the same in the case of *T. nilotica* in the presence of a floating pellet or within a relatively large cage. But with ordinary pellets the feeding box used in small cages of 1 m^2 area considerably reduces feed losses, especially if the water is rough and a strong current passes through the cage (Coche, 1977).

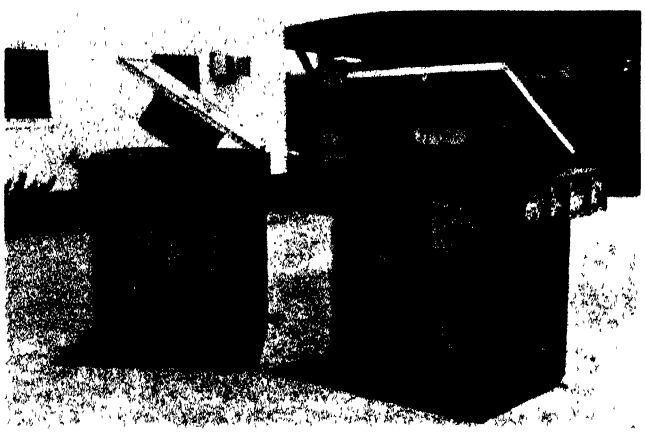


Fig 3. Floating cage from Lake Kossou with hardwood frame covered with mesh, lateral flotation by styrofoam blocks, top cover and feeding box. Rearing capacity of 1 m^3

5.4 *Shapes and dimensions of fish culture cages*

The shape most generally adopted for cages is box-like with a square or rectangular base. In brackish water Tatum (1973, 1974) used a cylindrical model adapted to research needs. Some more elaborate forms (octagonal, decagonal, dodecagonal, for example) have been studied in industrial mariculture (Milne, 1972; Anon., 1973b). Today in Norway the most popular floating cages are of octagonal shape (D. Møller, personal communication).

The dimensions of culture cages vary considerably (in general from 1 m^3 to more than 100 m^3) according to the kind of construction material used, the type of culture practised and the local conditions (Table II) (see pages 434–5). For research purposes cages of small capacity (0·7–10 m^3) are generally preferred. For the commercial production of catfish in the United States (250 kg/year per cage), Kelley (1973) recommended a capacity of 1 m^3 to facilitate handling and harvest. In contrast, in the Far East (except in Indonesia) cage dimensions are much larger, sometimes reaching 150 m^3. Similar capacities are also currently used in European mariculture (Milne, 1972; Dahm, 1975), but in the Federal Republic of Germany the net cage recommended for salmonid production does not exceed 27 m^3 (3 × 3 × 3 m—Kuhlmann, personal communication). In the Netherlands the intensive production of rainbow trout and carp is carried out with great success in net cages of only 6·5 m^3 capacity, grouped together in fours to make production units of 26 m^3 each (Huisman, personal communication).

It would therefore appear that the choice of very large cages is not *a priori* advisable. It results in the loss of several inherent advantages of the cage culture method (Table I), mainly flexibility of management and manoeuvrability. The risks of fish losses also increase. On the other hand, the investment costs increase in the case of small cages. It remains, however, to be demonstrated, for *T. nilotica* in particular, that large capacity cages (more than 20 m^3) offer real advantages in comparison to small cages. Such a demonstration has not yet been carried out in the United States for catfish production (Kelley, 1973). For *S. gairdneri* it has been shown that a lower limit of capacity exists for guaranteeing good feed conversion rates (Koops, 1969); cages have to be sufficiently large to reduce feed losses through the walls caused by turbulence created as the trout feed voraciously.

5.5 *Maintenance of fish culture cages*

It is essential to maintain culture cages in good condition, especially to reduce as far as possible the loss of fish (in particular when using a net cage) and to optimize fish production. In Japan, for example, cage netting may be replaced every six months.

One of the most important types of maintenance, particularly in brackish water, consists of periodic cleaning of cage walls (Milne, 1972). The walls can quickly become the support for thick biological growths (algae, mussels, barnacles) which, by reducing water exchange, negatively influence fish growth. This scrubbing is particularly difficult and labour-consuming with net cages. To reduce its

frequency, nets can be chemically treated. The use of a copper salt on synthetic fibre reduces fouling by 50% (Brett, 1974). Tar is also effective (Dahm, 1975). In the Federal Republic of Germany, H. Kuhlmann (personal communication) specifically recommends the use of Wiedox Grün (Wiederhold-Farbwerks) every two years. Nets can also be easily replaced without any handling of fish. One net dries on land while the other is in the water.

This problem of fouling of submerged cage parts was discussed at length by Milne (1972) who, after numerous experiments in littoral waters of Scotland, concluded that galvanized metal was superior in this regard. In fresh water this problem is generally less bothersome, although in certain conditions the cage walls can be excessively colonized by bryozoans and sponges (Dahm, 1975).

A biological method of controlling fouling of cage walls in brackish water was used by Tatum (1974) who recommends adding 30 *Mugil cephalus* (average weight 20 g each) per m^3 of cage. At Kossou it was observed that *T. nilotica* browse on available algal colonies (*eg, Spirogyra* spp.) which may develop on the cage walls (Campbell, personal communication).

Cages constructed from wood (Fig. 4) can be seriously damaged by larvae of *Povilla adusta* (Fig. 5) (see page 435). This mayfly species is widely distributed in Africa and notably in East Africa where it is well known by boatbuilders for the serious damage done to submerged wooden structures (Corbet, 1957; Hartland-Rowe, 1958). The quality of the wood appears to greatly influence the frequency of borings; hardwoods (*eg*, mahogany—*Khaya* spp.) being only slightly attacked after one year of immersion in Lake Kossou.

Finally, it should be noted that under certain limnological conditions, notably when the tannic acid level in the water is high, corrosion of metal cage parts can proceed very rapidly even in fresh water. For efficient protection Kelley (1973) recommends the use of a special black paint (Lagotex).

5.6 *Effects of the design and location of cages*

The possible effects of the presence of an opaque cover and of a feeding ring have been discussed. The choice of mesh size to be used on the cage sides, however, remains of fundamental importance.

Too low a rate of water renewal can strongly decrease fish production (Schmittou, 1969). The total open area (spaces) on the sides of cages should therefore be as large as possible. For example, Netlon plastic mesh with 8 mm meshes only provides 60% openings while 24 mm meshes offer as much as 85%; however, such large meshes limit rearing to individual *T. nilotica* weighing not less than 25 g. It thus appears that for this species a rigid 20 mm mesh would be preferable for initial stocking of smaller fish. For *I. punctatus* R. A. Collins (1970) recommends a mesh size of at least 13 mm (bar).

In the case of flexible netting it is preferable to refer to the minimum mesh size for gill entanglement of the fish cultured. For example, for trout-like fish, Kuhlmann (personal communication) recommends that the mesh size be less than one tenth of the length of the stocked fish. For *T. nilotica* a mesh size of 25 mm (bar) requires a stocking size of at least 70 g live weight.

On the other hand, the smaller the mesh size the faster the openings may become clogged by aquatic organisms. The dissolved oxygen concentration in the cages can then easily reach critical levels, adversely affecting the fishes and even endangering their survival. A good location for cages can also be important. If they are placed within a large water mass they should be located where wind-induced currents are favourable. This can contribute to reduced risks of lowered production and increased mortality. The inspection and maintenance of cages would have to become more frequent, thus increasing production costs.

Net cages generally need protection on the outside against possible attacks by aquatic predators. In this regard, either a second net of stronger twine (Figs. 1 and 2) or a lightweight meshed wire may be used (Landless, 1974). The mesh size of this outside netting should be large enough to maintain minimum water exchange. The location of cages is thus very important, particularly if the water mass tends to stagnate, with little renewal. A sufficient quantity of oxygenated water needs to be assured throughout the testing period to optimize production (Coche, 1977). Preferably, cages have to be placed perpendicularly to the principal water currents in relatively shallow water where a continual total circulation is maintained. A water depth of at least 2–5 m is, however, advisable to keep the cages far enough from the bottom where numerous parasites may occur or where unconsumed food may accumulate. In the latter case it would be advisable to move the cages to a site where water circulation is more complete.

5.7 *Experimental floating cages in the Ivory Coast, Africa*

The experimental floating cage used in Lake Kossou (Coche, 1975) has a rearing capacity of 1 m^3. Constructed with hardwood (mahogany—*Khaya* spp.) and covered on five faces with plastic meshed netting it has a dry weight of about 40 kg. The use of metal netting practically doubles the weight, thus reducing the manœuvrability of the cage and increasing the flotation requirement.

The culture cage consists of four distinct parts. (*a*) *The cage proper*: a wooden frame is assembled with reinforcements at the corners and on the bottom (Fig. 4). This frame is covered on five of its faces with plastic netting (black Netlon) with mesh openings of 24 mm^2. The fibre is 2 mm thick; (*b*) *The two floats*: blocks of styrofoam ($0{\cdot}1 \times 0{\cdot}2 \times 1$ m) laterally attached to the wooden frame (Fig. 3). (*c*) *The opaque cover*: marine plywood fixed to a wooden frame. A small mobile hatch (Fig. 3) is placed in the centre over the feeding box which is also made of marine plywood. This box extends 20–25 cm into the water. (*d*) *The feeding tray*: wooden platform attached laterally across the cage and permanently submerged 30–35 cm below the water surface. It appears that it might not be necessary and experiments are now in progress to see if it could be eliminated (Fig. 4).

6 The feeding of fish in cages

6.1 *Type of feeding*

The artificial food used in the majority of cases (except *eg*, in Indonesia) represents the sole nutritive source for fish confined in cages at a relatively high population density. The composition and presentation of the food therefore greatly influence fish production and the conversion rate.

The feeding of fish in cages varies according to locally available feeds, species cultured and the type of culture practised (Table II). In traditional fish culture the feeds

Country Type of fish culture	Fish species	Initial stocking Type	No.	No./m³	kg/m³	Type of cage and environment	Period days months	Av. Fish yield Type	kg/m³	Fish Production kg/m³	Artificial feeding Type	Daily ration	Conversion Rate	Reference
IVORY COAST Kossou Experimental 1974	*T. nilotica* (General averages)	9–55 g (29 g)	215–488 —	215–488 (340)	2–21 (9.8)	1 m³ floating cages in large reservoir	92–164 d (125 d)	157–271 g (197 g)	35–76 (61·1)	35–64 (50 8) 12·9/mo	Pellets, prot. 25%	3–6% once/d	2 6–3·7 (2·8)	Coche 1977
Alabama, USA Experimental	*T. aurea*	13·6 g	—	286–857	3·9–11 7	0 7 m floating cages in ponds	156 d	(?)	(?)	(?)	Intensive floating pellets	(?)	1·2–1·7	FAO 1970b
TANZANIA Experimental	*T. zillii*	2·6 g 53 mm	3 538	83	0 216	Floating net cages in Lake Victoria (a) 3·5 × 3 5 × 3 5 m 43 m (8 mm mesh) (b) 5 × 5 × 5 m 125 m³ (20 mm mesh)	3 mo	15·6 g 91 mm	(1·25)	(1·0)	Brewery wastes and fish meal (10:1) + leaves	15–30% 50% once/d	(?)	Ibrahim, Nozawa and Lema 1975
	T. esculenta	19 g 98 mm	2 362	19	0·360		6 mo	46·6 g 142 mm	(0·84)	(0 48)				
	T. zillii + *T. esculenta*	16·3 g 90 mm	936	22	0 360		5 mo	83·1 g 82·2 g	(1·74)	(1·38)				
KAMPUCHEA—THAILAND Traditional	*Pangasius* spp. Catfish	80–100 g	7 500	46–100	4–10	Floating cages in bamboo or planks 40–75 m × 2 m along river banks	8–10 mo	1 000–1 200 g	(80)	—	—	—	—	Hickling 1962
Semi-traditional	*P. sutchi* (50%) *Ophiocephalus* (33%) *C. batrachus* *Puntius* spp.	—	—	—	10–30 followed by heavy mortality	About 1 000 cages (av 4 × 2 × 3 m) Fish yield 4 000 t/year Along river banks	—	—	Annual 160	—	Fish, rice, bran, maize and vegetable	10–15% 4–6% in 2–3 times	8–10	FAO 1970 Ling 1967
THAILAND Semi-traditional	*Pangasius* spp. Catfish	Finger-lings	—	150–300	—	Floating cages	—	—	—	—	Fish, rice, bran	—	(?)	Bardach, Ryther and McLarney 1972
INDONESIA West Java Semi-traditional	*C. carpio* Common carp	8–12 cm	200–400	176	2 6	Bamboo cages standing on bottom in shallow rivers. Enriched organic 2·25 × 1·2 × 0·65 m Av. 1 7 m³	4 mo	180–200 g	2–3 mo 37	—	Natural food	Nil	—	Hickling 1962 Huet 1956
JAPAN Commercial	*C. carpio*	70 g	3 500	194	13·6	Floating net cages 9 m² × 2 m—lakes	6–8 mo	800 g	—	—	Intensive	(?)	(?)	FAO 1969
Experimental 1963	*C. carpio*	80–100 g	—	30–35	2·0 (0 7–4 5)	Floating net cages 7–81 m² × 2 m—lakes	3–5 mo	400–600 g	10–33	7·5–20	Intensive	(?)	1·1–2·5	Kuronuma 1968
USSR Experimental 1965	*C. carpio*	40 g	—	100–250	4 2–9 75	Floating net cages 3 m² × 1 m Lakes and heated effluents	3 5 mo	390–480 g	48–98	40–90 (26/mo)	Intensive vegetable + 10–15% anim. prot.	25–50% in x meals	(?)	Gribanov, Korneev and Korneeva 1968
THE NETHERLANDS Experimental 1974/75	*C. carpio*	—	—	—	25	Floating net cages 6 5 m³ in heated effluents	6·5 mo	—	189	164	Intensive pellets autom. distr	—	1·64	Huisman personal communiction
USA, Various Commercial	*I. punctatus*	15 cm 30 g	—	390	—	Floating cages Ponds and lakes	6 mo	650–700 g	—	—	Floating pellets	3–11%	—	R. A. Collins 1970b
Texas, USA Commercial	*I. punctatus*	—	—	—	38–99	1 m³ floating cages in heated effluents	30 d	—	69–178	30–79	Floating pellets	4% twice/d	1 3	R. A. Collins 1970a
Oklahoma, USA	*I. punctatus*	12·23 cm 25–60 g	216–360	216–360	5·4 to 21·6	1 m³ floating cages (metal) in lakes	7–9 mo	380–570 g	97–197	91–175 (20/mo)	Purina Trout Chow	1·75–6% once/d	1·4–1 7	C. M. Collins 1972
Alabama, USA Experimental	*I. punctatus*	20 g	—	400–500	8–10	Floating cages (metal) in ponds	5–6 mo	450 g	180+	—	Purina T.C floating	(?)	1 25	FAO 1969c

Experimental	*I. punctatus*	194 g	—	300–500	38–94	Floating cages (metal) 1–2 9 m³ in ponds	40 d	—	180+	57–89 (73 3)	Purina T C floating	1 5–4%	1 0–1·6	Schmittou 1969
S. Nebraska, USA Experimental	*I. punctatus*	15 g	490–500	216	3–3·3	Floating cages in reservoir —2 29 m³	161 d	220–285 g	35 5–57	32–54	Purina T.C. floating	(?)	1 2–1·3	Feit 1971
S. Illinois, USA Experimental	*I. punctatus*	12–15 cm 25–30 g	200	286	7–8	Floating cages 0·7 m in lake	Season	750 g	—	—	(?)	(?)	(?)	FAO 1970a
S. Illinois, USA Experimental	*S. gairdneri* Rainbow trout	—	—	242	—	Floating cages in lake	Cold season	—	33+	30·3	Intensive pellets	(?)	(?)	FAO 1975
Arkansas, USA Experimental	*S gairdneri*	56·7 g	400–700	274–480	15 5–27 2	Floating cages 1·458 m³ in lake	Cold season 115 d	163 g	45–80	27 6–55 3	Intensive pellets	(?)	1·4–1·7	R. A. Collins 1972
CHILE Experimental	*S. gairdneri*	6–8 g	3 200–6 400	40–80	0·25–0·65	Net floating cages 4 × 4 × 5 m in lake	12–14 mo	150–200 g	4·6	(4·6)	Intensive pellets	(?)	1·6–2·0	Arroyo 1973
HOLLAND Experimental 1974/75	*S. gairdneri*	—	—	—	21 9	Net floating cages 6 5 m³ in heated effluents	4 mo	—	65	43	Intensive pellets autom. distr.	—	1 83	Huisman personal communication
CANADA, Quebec Experimental	*S. fontinalis* Brook trout	10–15 cm	1 200	53	—	Net floating cage 22·656 m³ in lake	—	—	—	—	—	—	—	Séguin 1970
JAPAN Commercial	*S. quinqueradiata* Yellowtail	5–10 cm 10–50 g	1 500–2 500	10	0·15–0 55	Net floating cages 144 m³ Marine bays	7 5 mo	1 000–2 000 g	10–15	—	Fresh trash fish	Intensive (20–25%) twice/d	6–7	Ling 1973
Alabama, USA Experimental	*S gairdneri* Rainbow trout	93 8 g	—	196–392	18·4–36 8	Floating cages 0 76 m³ —Marine bays	4 mo	317–355 g	(103+)	29–65	Purina T.C.	3–5% twice/d	3·3–4·7 (mort.)	Tatum 1973
Florida, USA Experimental	*T. carolinus* Pompano	7–12 g	100–900	100–900	0 7–6 3	Floating cages 1 m³ —Marine bays	11–12 mo	(450 g)	(50+)	23–38	Purina T.C.	5%, 1–3 meals	2·7–3·6	FAO 1973 Tatum 1974
Washington, USA Experimental and Commercial	*Oncorhynchus* spp. Pacific salmon	10–20 g	—	(?)	(?)	Floating cages 50 × 12 × 3 m = 1 800 m³ in marine bays	7 mo	300–400 g	(16+)	—	Oregon pellets	(?)	1·0	Anon. 1973 Milne 1972



Fig 5. Damage caused by *Povilla adusta* larvae to a submerged cage structure made of softwood after 13 months of continual immersion

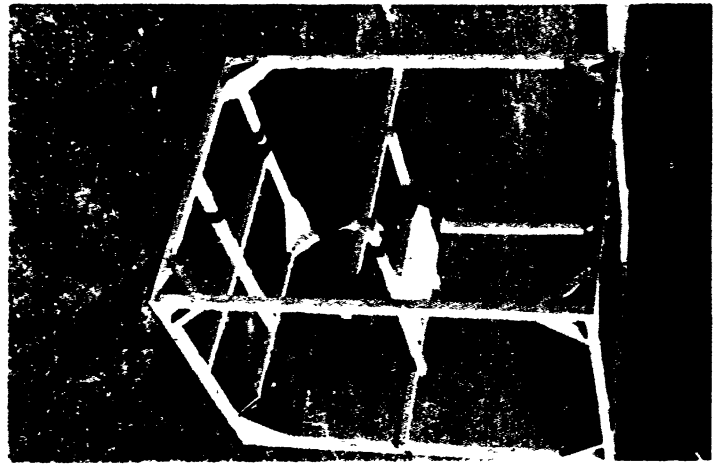


Fig 4. Wooden frame of Lake Kossou experimental cage with reinforcement at the corners and the bottom. The wood is mahogany (*Khaya* spp.) cut into runners 3 × 3·5 cm thick. Overall dimensions: 1 × 1 × 1·3 m. Note transverse feeding tray in this particular model

mainly comprise local untreated by-products (rice, rice bran, maize, brewery wastes, fresh trash fish) which are placed in the cages (Kampuchea and Thailand). In commercial enterprises, similar feed is only preferred (*eg*, in Japan) in the absence of industrial feed (a mixture of local by-products), balanced (vitamins and minerals) and processed into water-stable pellets (USA and Europe). These pellets are mainly used for commercial production of trout, carp and American catfish. They are normally non-floating, but floating pellets would appear to be preferable for distribution in cages, their consumption and loss being more easily and better controlled. However, the preparation of floating pellets requires the use of high temperatures which apparently results in the deterioration of vitamin C[1].

In super-intensive cage culture the food most often used in the United States appears to be a trout feed for raceway culture (*eg*, Purina Trout Chow with 40% protein) as well as a special floating feed for catfish (*eg*, Purina Catfish Cage Chow with 36% protein). At Kossou, non-floating pellets largely made of chicken feed (24·7% protein) have given very satisfactory results (Coche, 1977).

6.2 *Daily food ration*

In cage culture the quantity of natural food accessible to the fish is generally insignificant. The choice of a daily food ration in view of optimum utilization of the artificial feed then becomes much more important than in earth pond culture. This choice is made more difficult because the relationship between feeding rate (expressed in percentage of live fish weight) and conversion rate of this food is mainly a function of the fish species cultured, the size of the individuals, the food quality and the water temperature. There is very little information on this subject for fishes in general; for *T. nilotica* in particular, it is practically non-existent.

For *T. nilotica* fed in ponds with very rich pellets (46% protein), Swingle (1967) recommends a daily ration of 3–5% of the fish biomass. With 35·7% protein, Hastings (1973) chose a daily ration of 4% biomass. For optimum growth rate, *I. punctatus* consumes 3% of its live weight daily until reaching a size of 500 g, and then 2% (Ghittino, 1972). The quantity of food necessary decreases as the individual fish size increases (Phillips, 1972) although there is very little information on the exact extent of this relationship (Shell, 1967). Moreover, the required feeding rate increases with the water temperature. These variations partly explain the apparent inconsistency of the daily food rations used in cage culture (Table II).

At Kossou *T. nilotica* reared in cages were fed with pellets containing 24·7% protein on the basis of 6% of the initial monthly biomass. In practice, it amounted to 3–6% of the fish biomass present in the cages. From the results obtained (Coche, 1977) it appears that this ration is valid for individuals smaller than 40 g on average. Above this size, the daily ration should not exceed 4% of the biomass in order to obtain a reasonable conversion rate. The energy value of the pellets used was relatively high (about 3 500 Cal/kg) thus reinforcing this opinion[2].

It has been demonstrated that division of the daily ration into several smaller rations can play an important role (Shell, 1967). The need to reduce the interval between two feedings to at least 12 hours was demonstrated for *Trachinotus carolinus* (Tatum, 1974) and for young *I. punctatus* (R. A. Collins, 1970b), but such a regime does not appear to be necessary for *I. furcatus* (R. A. Collins, 1970b). *T. nilotica* has no true stomach and the capacity of its intestinal bulb is relatively small. It would therefore appear to be advisable to divide the food ration into several feedings. In this case, the daily ration could probably be increased while still giving an advantageous production and conversion (Shell, 1967a). This increase in the frequency of the feedings is equally justified by the relatively slow digestion rate observed in *T. nilotica*. For example, brewery wastes require as much as 12 hours to be digested while *Clarias lazera* can digest such food in only 6 hours (Micha, 1973).

6.3 *Conversion rate of artificial feed*

The conversion rate of artificial feed in cage culture reflects the interaction between the fish (size and density), the food (quality, ration and distribution) and the physico-chemical environment (in particular water temperature, dissolved oxygen concentration and renewal rate of water in the cage). Among all parameters of fish production the feed conversion rate has been shown as that which is most affected by unfavourable cultural conditions (Schmittou, 1969). For an identical food ration, utilization of the given feed decreases as the individual size of the fish increases, or if the stocking density is too low or too high. On the other hand, the relationship between the feed conversion rate and the daily ration being parabolic, utilization also decreases on either side of an optimum ration.

Finally, feed utilization can be greatly diminished if feed losses through cages are too high. Generally these losses are mainly caused either by the fish themselves during the distribution of the pellets (excessive agitation), or by a strong water current washing the food outside the cage. R. A. Collins (1970b) even reports to have lost up to 25% of the given feed due to the presence of a dense wild fish population around the cages. These fishes quickly learned how to create the water movements necessary to remove the distributed pellets from the cages, and it was necessary to set traps to successfully control these wild fish.

In intensive culture of fish in cages the conversion generally varies between 1·2 and 1·7 kg floating pellets used per kilogramme of fish produced (Table II). In the United States a floating pellet rich in energy (40% protein) gave a conversion rate of 1·3 with *I. punctatus* (C. M. Collins, 1972). In the German Democratic Republic the manual distribution of sinking pellets (about 35% protein) gave conversion rates of 1·6–2·3 with *C. carpio* (Steffens, 1970; Steffens *et al*, 1969) (Table III). In the Netherlands, an average conversion rate of 1·6–1·8 in the alternate cage culture of *C. carpio* and *S. gairdnerii* was obtained with automatic pellet feeding (Huisman, personal communication). The cage culture of *T. aurea* fingerlings in Alabama with a similar feed gave a conversion rate of 1·2–1·7 (FAO, 1970b), but in ponds, Swingle (1967) using pellets with 46% protein achieved, for the same species, values of 0·7–1·2 (average = 1·0). In concrete tanks Hastings (1973) experimented with protein percentages varying between 20% and 40%. He observed a minimum conversion rate of 1·1 for a 30% protein content. It increased to 1·8

[1] To compensate for this deficiency a concentrated solution of Vitamin C is sprayed over the floating pellets immediately before their distribution (R. A. Collins, personal communication)

[2] Taking into account a digestibility estimated for *T. nilotica* at 90% for proteins, 85% for lipids and 80% for carbohydrates, the energy value of the pellets still reaches about 2 900 Cal/kg.

TABLE III

RESULTS OF *C. Carpio* REARING IN 6·5 m³ NET CAGES IN HEATED EFFLUENTS OF POWER STATIONS IN THE GERMAN DEMOCRATIC REPUBLIC

Rearing period	*May to July 1967 (water t 25–30°C)*			*August to December 1968 (water t 27–17°C) 75 to 118 days*
	79 days		*41 days*	
Quality of pelleted feed Daily ration	*35% proteins 4·1–3·5% biomass*		*35% proteins 4–2·1% biomass*	*33·7% proteins 2·9–1·9% biomass*
Initial stocking rate, N/m³	160	320	230	100–196
Initial stocking rate, kg/m³	14	28	52	20–44
Initial average individual weight, g/fish	87·5	87·5	226	208–309
Final stocking rate, kg/m³ (yield)	66	109	112	91–175
Final average individual weight, g/fish	429	346	487	899–1 324
Mortality, % initial number	2	2	0	1·6
Average individual growth, g	342	259	261	652–1 015
Average individual growth, g/day	4·3	3·3	6·4	6–10·7
Production, kg/m³	52	81	60	70–131
Food conversion rate	2·2	2·2	1·6	1·6–2.3 (1·9)
Reference	Steffens *et al*, 1969			Steffens, 1970

and 3·3 for protein contents of 25% and 20% respectively. On the other hand, in another similar experiment, the minimum conversion rate (1·5) was found for a 40% protein content, a gradual increase in its value being observed as the protein content decreased. In Kossou (Coche, 1977) cage *T. nilotica* fed with sinking pellets containing about 25% protein gave, on the average, a conversion rate of 2·8. It would appear that by improving the quality of the pellet, by better adapting the daily ration to the specific needs of the fish and by fractioning its distribution, values below 2·0 could be obtainable with average fish densities (300–350/m³). As the density increases, the feed conversion rate improves, a phenomenon which appears to be general in cage culture (*eg*, Tatum, 1974).

The mechanization of feed distribution is becoming more and more common. It is, for example, utilized in fresh water in the Netherlands (Huisman, personal communication), in the Democratic Republic of Germany (Grave, personal communication) and in the USSR (Anon., 1974a). An important reduction in labour and better distribution of the feed are its principal advantages. According to Mann and Moeller (1971 cited by Dahm, 1975), the choice between automatic and demand feeders should be made in the case of *S. gairdneri* as a function of the water temperature. On the other hand, the use of a demand feeder does not appear to be economical in the presence of very high population densities. In Kossou, a simplified automatic feeder, operated by the movement of the water itself, was successfully used (D. Campbell, personal communication). By this method the feed distribution lasts for at least one hour in each cage (Fig. 6). The losses of pellets through cage walls as well as the time required for manual distribution are greatly reduced. Finally, efforts to increase the utilization of artificial feed have been made by increasing the quantity of natural food (insects) available to caged fish (Heidinger, 1970).

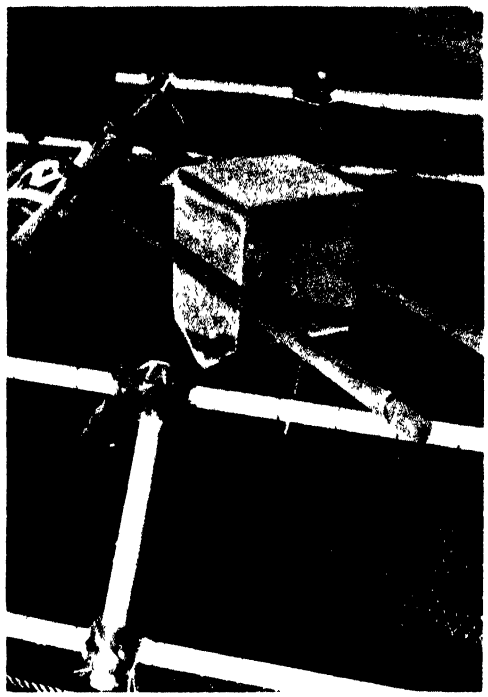


Fig 6. Simplified automatic pellet feeder in operation at Kossou in a 6 m³ net cage. The water surface movement causes a set of cords to liberate small quantities of feed (*photo — D Campbell*)

7 Growth of cage-reared fish

The average individual growth of fish reared in cages dereases when the physico-chemical conditions of the environment become unfavourable. For example, small meshes which reduce water renewal can significantly reduce the growth of *I. punctatus* even in the absence of fouling (Schmittou, 1969). In Kossou a similar decrease in the growth of *T. nilotica* was observed when the dissolved oxygen concentration in the cage reached critical levels following the complete turnover of the water mass (Coche, 1977).

The growth rate also decreases as the fish biomass per unit of water volume increases (Tables III and IV). This phenomenon has been observed in cages for practically all the cultivated fish species: *I. punctatus* (C. M. Collins, 1972), *T. carolinus* (FAO, 1973; Tatum, 1974), *C. carpio* (Gribanov *et al*, 1968), *S. gairdneri* (Tatum, 1973), *T. aurea* (FAO, 1970b) and *T. nilotica* (Coche, 1977). On the other hand, the average growth rate increases as the food ration increases, the maximum growth rate not necessarily corresponding to the optimum food utilization (Shell, 1967a).

In fresh water cage culture *C. carpio* generally demonstrates the fastest growth rate, 40–80 g fish attaining more than 400 g in about four months (Table II)[1]. In six to eight

[1] In Hungary the best growth was observed with *Silurus glanis*. Fingerlings of 23 g reached an average weight of 275 g in 159 days (Csávás, personal communication)

months it can reach 800 g or more when the initial stocking rate is average (maximum of 14 kg/m³). In heated effluents (25–30°C) carp held at this stocking rate have grown to 343 g in 79 days on an average (Table III). At a doubled stocking rate the individual growth still averaged 260 g (Steffens *et al*, 1969). In slightly colder water (27–17°C) the growth varied between 650 and 1 015 g in 75 to 118 days (Steffens, 1970). The growth of *I. punctatus* also appears to be very good, reaching more than 700 g in one growing season of 7–8 months at low densitites (7–8 kg/m³). *S. gairdneri* gives a much lower average weight gain; a little more than 100 g in four months. From the point of view of growth in cages, *T. nilotica* appears to be intermediate between the two groups. In standard trials in Kossou, the average growth in three months varied from 120–200 g.

T. nilotica is characterized by sexual dimorphism and the growth of the males is much higher than that of the females. In ponds and in monosex culture Micha (1973) observed that the average growth rate of the males was more than 2·5 times higher than that of the females after three to four months of rearing. In Kossou the cage culture of a monosex male population equally demonstrated a better overall growth rate compared to standard populations (Coche, 1977), the average growth being 150 g and 220 g in three and four months respectively.

8 Stocking rates and production

The production of fish in cages decreased under unfavourable physico-chemical conditions. For example, a reduction of water exchange by the use of small meshes (6·4 mm instead of 12·3 mm) lowered the production of *I. punctatus* by 50% (Schmittou, 1969). While rearing *T. nilotica* in Lake Kossou, a comparatively lower production was observed following the deterioration of the oxygen content of the water due to the annual thermal cycle (Coche, 1977).

The stocking rate of fish in intensive cage culture varies according to the species, generally between 15 and 25 kg/m³, but the total production increases with increase in the initial biomass (Tables III and IV) up to the optimum rate. Beyond a certain density, at least with *S. gairdneri* (Albrecht and Gollub, 1971), it appears that the fish live under constant stress which adversely influences their growth.

The holding capacity of a cage can be very high, as in American catfish culture (*I. punctatus* more than 220 kg/m³—R. A. Collins, personal communication) and in the Dutch culture of *C. carpio* (at least 189 kg/m³—Huisman, personal communication). In Arkansas the holding capacity of one cage containing *S. gairdneri* reached 80 kg/m³ (R. A. Collins, 1972) and in Alabama more than 100 kg/m³ (Tatum, 1973). In Florida 166 kg/m³ was achieved with *T. carolinus* in brackish water (FAO, 1973). Compared to the above values, the highest holding capacity (76 kg/m³) reached in 1974 in Kossou with *T. nilotica* reared for four months in cages (Coche, 1977) could be considered as relatively low. It is most likely that the maximum holding capacity has not been reached, and that it would probably approximate 100 kg/m³.

The maximum production corresponds to the maximum final holding capacity of a cage. For *C. carpio* the maximum production appears to be relatively high (Table III). In 109 days it reached at least 131 kg/m³ in the Federal Republic of Germany (Steffens, 1970). In the Netherlands in 6·5 months it attains more than 160 kg/m³ (Huisman, personal communication). In nine months, *I. punctatus* production was close to 175 kg/m³ (C. M. Collins, 1972). For *S. gairdneri* it appears to vary between 55 and 65 kg/m³ (R. A. Collins, 1972; Tatum, 1973). For *T. nilotica* the maximum production was estimated in 1974 to be about 70 kg/m³ (Coche, 1977).

The mortality of fish reared in cages is generally low if correct cultural practices are adopted. In the USA, it varies for *I. punctatus* between 2 and 10% over an average period of eight months (C. M. Collins, 1972). In Alabama, for fishes initially weighing 194 g each, it did not exceed 0·4 to 0·8% over 40 days (Schmittou, 1969). In the case of high densities of *S. gairdneri* the mortality was only 0·6% in four months (R. A. Collins, 1972). With *T. nilotica* the

TABLE IV

SELECTED DATA FOR INTENSIVE FISH CULTURE IN FLOATING CAGES (CF TABLE III). THE AVERAGE PRODUCTION RATE (APR) IS EXPRESSED IN PERCENT OF THE AVERAGE BIOMASS AND PER DAY

Fish species	*Initial stocking rate per m³*			*Rearing period*		*Yield/m³*		*Average Individual Growth (g/100 d)*	*Production*		*Reference and remarks*
	No.	*Average wt. (g)*	*Biomass (kg)*	*Days*	*Average biomass (kg/m³)*	*Average wt. (g)*	*Biomass (kg)*		*kg/m³*	*APR %/d*	
T. nilotica, average 9 cages	351	29	10·5	121	39·0	210	67·6	150	56·5	1·20	Coche 1977
Kossou, Ivory Coast	355	40	14·2	122	43·9	228	73·6	154	64·0	1·19	Coche 1977
Kossou, Ivory Coast	488	40	20·5	92	64·2	168	71·9	139	51·5	1·21	Coche 1977
I. punctatus, Alabama, USA	350	15·4	5·4	115	36·0	268	66·6	220	61·2	1·48	Schmittou 1969[a]
Alabama, USA	3–500	193	77·6	40	114·3	370	150·9	443	73·3	1·60	Schmittou 1969[b]
S. Nebraska, USA	215	14	3·0	161	30·0	280	56·7	165	53·7	1·11	Feit 1971
Oklahoma	360	25	9·0	230	72·0	383	135·0	156	126·0	0·76	C. M. Collins 1972
Oklahoma	360	64·3	23·1	230	109·7	563	196·4	217	173·3	0·69	C. M. Collins 1972
S. gairdneri, range	—	—	—	—	—	—	—	—	—	0·8–1·3	Steffens 1971
Arkansas, USA	267	56·7	15·1	115	40·2	245	65·3	164	41·8	0·90	R. A. Collins 1972
Arkansas, USA	507	56·7	28·7	115	73·4	236	118·0	156	74·6	0·88	R. A. Collins 1972
Alabama, USA	392	93·8	36·8	120	51·0	320	102·0	189	64·7	1·06	Tatum, 1973[c]
C. carpio, German Dem. Rep.	160	86	14·0	79	40·0	429	66·0	434	52·0	1·65	Steffens *et al*, 1969[d]
German Dem. Rep.	320	86	28·0	79	68·5	346	109·0	329	81·0	1·50	Steffens *et al*, 1969[d]
German Dem. Rep.	230	223	51·3	41	81·6	487	112·0	644	60·8	1·82	Steffens *et al*, 1969[d]
German Dem. Rep.	100	284	28·4	75–109	70·8	1 144	113·3	555	85·0	1·29	Steffens 1970[de]
German Dem. Rep.	120	282	33·8	76–118	77·7	1 030	121·5	771	87·7	1·15	Steffens 1970[e]
German Dem. Rep.	196	226	44·3	109	109·5	910	174·8	628	130·5	1·09	Steffens 1970[f]

Remarks: (*a*) 12 cage average, (*b*) 6 cage average, (*c*) in brackish water, (*d*) in heated effluents, (*e*) average 10 cages 6·5 m³ each, (*f*) average 4 cages 6·5 m³ each

average mortality was 5·9% (3–6 months), a value to be considered as a maximum (Coche, 1977). The mortality rate can, however, considerably increase if fry are stocked initially.

The resistance of fish to diseases and parasites is particularly important in cage culture because the population densities are relatively high. *I. punctatus*, for example, appears to be somewhat susceptible to bacterial diseases (C. M. Collins, 1973). On the contrary, *T. aurea* was apparently resistant to diseases and parasites in Alabama (FAO, 1969a). In Africa it has not yet been demonstrated that this is also the case with *T. nilotica*. Several serious cases of mycosis were observed in 1975 in Ivory Coast which gravely affected the growth of the fish. In Lake Victoria *T. esculenta* and *T. zillii* were similarly attacked (Ibrahim *et al*, 1975).

Finally, the potential of a fish species is directly related to its survival rate in cages even under occasionally unfavourable conditions. From this point of view, it would appear that *T. nilotica* has a great potential for cage culture. Physiologically this species is characterized by high thermal tolerance and a relatively low metabolic rate. At 25°C the oxygen consumption of 2 g fingerlings is only 14·8 cc/h/100 g live weight which is 3·7 times less than for similar *S. trutta* fingerlings reared at their optimum temperature (Denzer, 1968). The metabolism per unit of weight decreases as the fish size increases. *T. nilotica* appears to become particularly resistant to a temporary deficiency in dissolved oxygen when larger than 20 to 30 g live weight. This was confirmed by the observations made in Kossou where no mortality was observed in the cages following a period when the dissolved oxygen content at the beginning of the day was only 0·7 mg/l at 26·7°C, which corresponds to about 9% saturation (Coche, 1977).

The net productions achieved under experimental and commercial conditions (Table II) vary considerably. They may be summarized as follows:

Fish species	*Production kg/m³*	*Production kg/m³/month*
C. carpio	7·5–164	2–35
I. punctatus	30 –175	6–19
S. gairdneri	27 – 60	7·15
T. nilotica (Kossou)	34 – 64	6–17

If the production rate is expressed in percent of the average biomass per day (average production rate—APR), it appears that it varies relatively little and in general 0·8–1·6% for the four principal species when intensively cultivated (Table IV). The highest values (1·6–1·8%) are recorded for *C. carpio*. They are generally greater than 1% for *I. punctatus*, but this value seems to be only exceptionally reached by *S. gairdneri*. Values close to 1·2% were attained with *T. nilotica*.

The observed production during the first year of *T. nilotica* cage culture in Kossou therefore appears to be very encouraging. This is particularly so if it is considered that in a tropical climate favourable conditions for such culture might exist for at least 300 days each year, 2–3 crops being produced annually.

9 Fish yield

From the economics standpoint, efficient cage culture is not necessarily that which produces the highest quantity of fish. The efficiency, in fact, consists of producing fish of good market value with an acceptable food conversion rate during a given period of time and in a quantity that is economically beneficial.

Cage-reared fish are preferably marketed fresh, generally after three to eight months of growth, depending on the artificial feed used and the market value of the fish. The market size varies from one species to another and for the same species it may vary by country and even by season. *C. carpio* (except in Indonesia) and catfish (in Asia particularly) are sold at a relatively large size, more than 600 g in general (Table III). Cage-reared trout and salmon produced for the growing luxury market of 'pan-size' fish have individual weight of approximately 225 g. The Atlantic salmon (*S. salar*) is sometimes raised to the relatively large size of several kilogrammes. The market size of tilapias varies enormously in Africa. In the Central African Empire it is at the most 100 g, while in the Ivory Coast it can often be over 250 g.

Very few detailed economic studies have been made until now on cage culture of fish. Menzel (1971) studied the economics of *S. gairdneri* culture in the German Democratic Republic. For the same country but for *C. carpio*, Steffens *et al* (1969) discussed cage culture in heated effluents of power plants and Albrecht *et al* (1976) studied the economics of large-scale cage culture. In a more general manner, C. M. Collins (1972) presented a comparative study for the cage culture of *I. punctatus* in the United States.

Within the stocking rate limits described earlier, the cost of fish production per kilogramme decreases and the total net profit increases as the initial biomass increases. Among the various cage culture techniques tested for *I. punctatus*, C. M. Collins (1972) obtained the maximum profit by rearing the largest fingerlings (20 to 23 cm) at the highest density (360/m³). Similarly, in Florida, with the cage-rearing of pompano the highest density (900/m³) gave the best profit, US$ 160 per cage in about eleven months (FAO, 1973).

These results therefore suggest that both from the economic and biological points of view, the best results are obtained with relatively high initial biomass. However, this type of cage culture is more delicate to operate. It requires a good circulation of clean and well-oxygenated water through the cages as well as intensive feeding, balanced and adapted to the fish population present in each cage.

The price of feed is a determinant in the production cost and, similarly, in the possible profits as demonstrated by Furukawa (1971 cited by Brett, 1974) for the culture of *Seriola quinqueradiata* in Japan. This species is mainly fed with fresh trash fish at the daily rate of 5 to 20% of the biomass.

The breakdown of average production costs (percent) according to the cultural method chosen are as follows:

PRODUCTION COSTS (PER CENT)

	Pond	*Net enclosure*	*Floating net cage*
Facilities	8·5	9·0	8·0
Depreciation	4·5	6·4	1·5
Labour	11·3	10·5	13·5
Seed stock	11·8	10·9	6·5
Feed	49·4	46·0	60·0
Operational costs	8·8	11·0	7·5
Miscellaneous	5·7	6·0	3·0

The feeding costs were highest in cage culture, reaching 60% of the total expenditure. In this particular type of culture an effort must therefore be made to reduce these costs to a minimum. This is the most urgent problem to overcome in Africa at this time.

10 Conclusions

Cage culture of fish presents numerous advantages, allowing a considerable increase in fish production in existing waters. This method is particularly well developed in the German Democratic Republic, Japan, Norway and the USA. From a general point of view, those countries are leading the technological progress in this field. Research is currently being pursued in numerous other countries and knowledge is increasing rapidly. It is important that research be intensified in Africa to adapt this new knowledge to the particular conditions prevailing there and to make the necessary modifications.

Of the fish species reared in cages, some seem to be particularly well adapted for Africa. From a general standpoint, *C. carpio* appears to be the best at the present time. Without doubt, the tilapias offer excellent potential, particularly *T. aurea* and *T. nilotica*. Under high altitude conditions, rearing of *S. gairdneri* in cages might be economically viable. However, experiments should be conducted with other African (*Clarias, Heterobranchus, etc*) or exotic (*eg*, Chinese carp) fish species which could be equally profitable in other conditions.

The basic technology for the design and the construction of culture cages appears to exist, and the difficulty lies in adapting the technology to local conditions. Floating cages are the most suitable. Of simple design and low cost, net cages are well adapted to artisanal use, even on a relatively large scale, but the inherent danger of this type of cage should not be forgotten. They have to be judged with due regard to higher investments needed to ensure success. From this point of view, a combination of hard wood and plastic mesh could perhaps be envisaged. The volume of the cages should not be too large and a rearing capacity of 20 m^3 appears to be the upper limit. For increased manoeuvrability and flexibility a cage capacity of 5–10 m^3 would be preferable.

One of the major requirements for success of cage culture is a high rate of water renewal. The mesh size of the walls and the location of the cages within a given water body are of primary importance to assure maximum growth rates. For intensive production, the feed has to be balanced, complete and adapted to the particular fish species. To achieve optimum utilization the daily ration should be adapted to the specific cultural conditions. As far as possible it should be fractioned. The mechanization of food distribution could also play a decisive role. In Africa the formulation of an adequate feed for intensive cage fish culture constitutes the major prerequisite for future development of cage culture.

The rearing of a high initial biomass minimizes the cost of fish production and maximizes the total net profit. The population densities should therefore be maintained at a high level which necessitates the initial stocking of a great number of fingerlings. This requirement brings out the problem of fingerling supply. The current methods of fry production of the cultured African fish species are not suitable for the production of fingerlings in very large numbers. They should be modified and intensified if the goal of increased fish production by cage culture is to be reached.

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The Development of a Commercial Pacific Salmon Culture Business

J. M. Lindbergh

Abstract

A joint pilot project was initiated by Domsea Farms, Inc. and the National Marine Fisheries Service in 1970 to rear coho (*Oncorhynchus kisutch*) and chinook (*O. tshawytscha*) Pacific salmon to market size. Juveniles were reared in heated fresh water and grown out to marketable size in floating cages located in salt water near Manchester, Puget Sound, USA. Although some problems were experienced in saltwater rearing with disease (*Vibrio anguillarum*), predators and facilities, the pilot project was considered successful and Domsea expanded the concept to a commercial venture in 1971.

The first large-scale facility design for cages in salt water was deficient, and serious problems resulted from structural failures, as well as disease and predation. Nevertheless, a crop of 655 000 fish weighing 213 000 kg was harvested in late 1973, and preliminary success was achieved with a captive broodstock of coho salmon. The net cage complex was then completely re-designed and performance to date has been excellent. No problems have been experienced with predators in the new facilities, and mortality from vibriosis has been significantly reduced through immunisation of juvenile fish.

Développement d'une entreprise commerciale d'élevage de saumons du Pacifique

Résumé

En 1970, la société Domsea Farms, Inc. et le Service national des pêches maritimes ont lancé un projet pilote conjoint d'élevage de saumon coho (*Oncorhynchus kisutch*) et de saumon royal (*O. tshawytscha*) de taille

marchande. Les jeunes étaient élevés tout d'abord dans de l'eau douce chauffée, puis—jusqu'à ce qu'ils atteignent une taille marchande—dans des cages flottantes en eau de mer près de Manchester, Puget Sound (Etats-Unis). Bien que l'élevage en eau salée ait donné lieu à quelques difficultés liées aux maladies (*Vibrio anguillarum*), aux prédateurs et aux installations, le projet pilote a été jugé satisfaisant et la société Dømsea l'a transformé en une entreprise commerciale en 1971.

Le premier ensemble à grande échelle de cages en eau salée s'est révélé inadéquat et de nombreux problèmes ont surgi du fait des imperfections structurales, ainsi que des maladies et des prédateurs. Toutefois, à la fin de 1973, 655 000 saumons d'un poids total de 213 000 kg avaient été prélevés, et un stock d'alevins captifs de saumon argenté a donné des résultats préliminaires intéressants. L'ensemble des installations (cages et filets) a donc été entièrement repensé et les résultats obtenus jusqu'ici sont excellents. Les prédateurs n'ont posé aucun problème avec les nouvelles installations et la mortalité par vibriose a été sensiblement réduite grâce à l'immunisation des jeunes poissons.

Desarrollo del cultivo comercial del salmón del Pacífico

Extracto

En 1970, la Dømsea Farms, Inc. y el Servicio Nacional de Pesca Marítima iniciaron un proyecto piloto conjunto de cría de salmón coho (*Oncorhynchus kisutch*) y chinook (*O. tshawytscha*) de talla adecuada para la venta. Los salmones se criaron hasta la fase juvenil en aguas dulce calentada y posteriormente, hasta alcanzar una talla comercializable, en jaulas flotantes en agua salada cerca de Manchester, Puget Sound, EE.UU. Aunque durante la fase de cría en agua salada se encontraron algunos problemas con enfermedades (*Vibrio anguillarum*), depredadores e instalaciones, se consideró que el proyecto piloto había tenido éxito y la Dømsea expandió en 1971 los trabajos hacia una empresa comercial.

El diseño de la primera serie de jaulas a gran escala para uso en agua salada fue deficiente y surgieron graves problemas debidos a fallos estructurales así como a enfermedades y depredaciones. De todas formas, a finales de 1973 se obtuvieron 655 000 peces, con un peso total de 213 000 kg, y se consiguió un primer éxito preliminar con una población de reproductores de salmón coho en cautividad. Por lo tanto posteriormente se diseñó de nuevo toda la serie de jaulas, y el rendimiento hasta la fecha ha sido excelente. En las nuevas instalaciones no se han observado problemas de depredación y la mortalidad causada por vibriosis se ha reducido notablemente gracias a la inmunización de las formas juveniles.

1 Introduction

Pacific salmon (*Oncorhynchus* spp.) in their natural environment spawn in inland rivers and lakes, and the young migrate to the sea where they live until mature. At this stage they return to their individual native streams and lakes to spawn and die shortly afterwards. The question might be asked, why pick such a fish to farm? General reasons are that the word 'salmon' is an old and esteemed name, the product has an attractive appearance, the flesh is tasty, and people are willing to pay a high price for it.

Artificial propagation of Pacific salmon has been practised for many years but the fish were released at a small size to migrate and forage at sea. Little attempt was made to cultivate them in captivity to marketable size until the US National Marine Fisheries Service (NMFS) in 1969 acquired migratory coho salmon, *Oncorhynchus kisutch,* and reared them in floating net pens in Clam Bay near Manchester, Washington (Fig. 1). These experiments were conducted to study survival and growth of adult salmon in captivity in salt water and problems that might be encountered in this rearing technique (Mahnken, Novotny and Joyner 1970). Dømsea Farms (then a division of Ocean Systems, Inc.) followed the experiment closely, and concluded that the results were sufficiently promising that, if the rearing programme could be scaled up from hundreds to several hundred thousands of fish, a viable business could be established.

2 Pilot programme

In 1970, NMFS worked with Dømsea to initiate a joint government-industry pilot programme (Lindbergh, 1972). Dømsea provided funds and personnel; NMFS provided technical services and space at the Manchester laboratory. A grant of US$ 100 000 was awarded by the Sea Grant Office of the US Department of Commerce to implement the pilot programme.

Working under the broad umbrella of an NMFS research

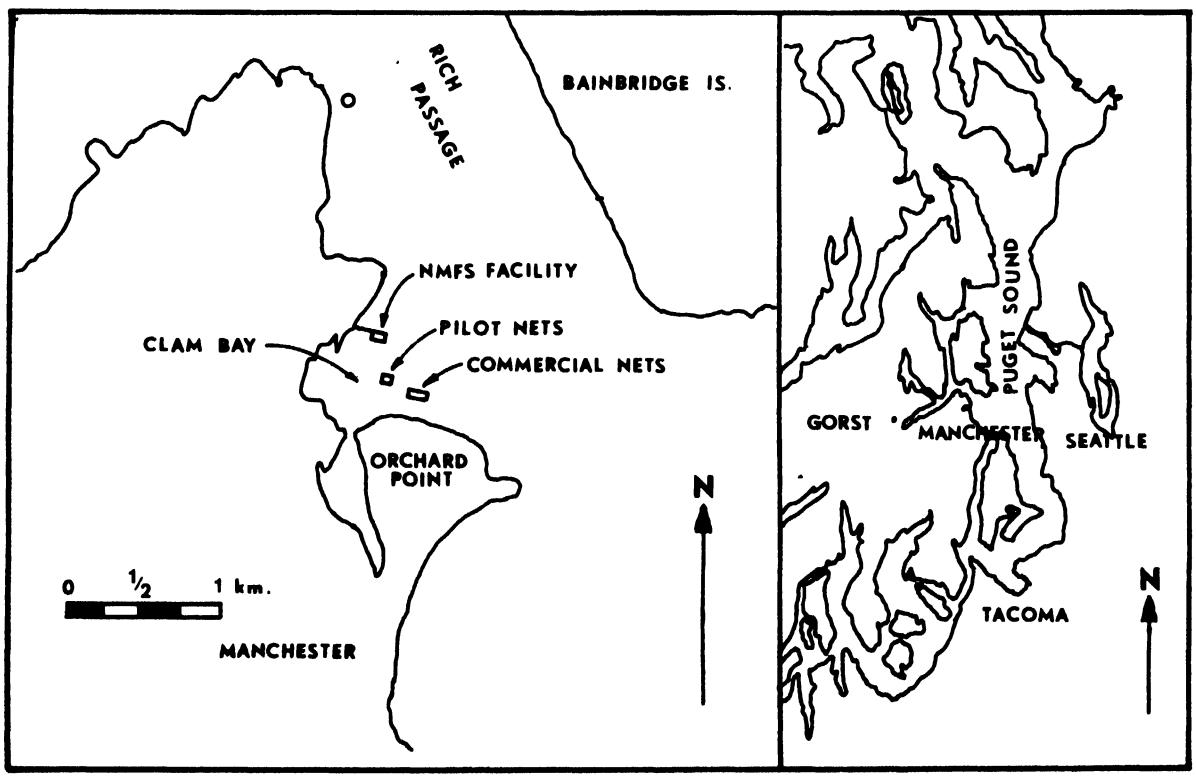


Fig 1. Location of NMFS, pilot, and commercial facilities

programme, a minimum of government regulatory problems were encountered. A small hatchery was constructed and coho salmon eggs were procured from the State of Washington for the first phase of the programme. Coho were selected as the primary species for the experiment because they are a hardy species with good resistance to disease, and preliminary data were available on their culture in salt water. They are also voracious feeders, accepting both wet and dry feed. Later, a second species was added to the programme, chinook salmon, *O. tshawytscha*. Chinook has the advantage of being able to adapt to salt water (smoltify) at about 7 g rather than at 15 g for coho.

2.1 *Freshwater phase*

The freshwater phase of the pilot programme was in general carried out according to standard salmonid rearing practices. Eggs were incubated in Heath-Teona trays and the fry reared in an earth-bottom pond (Glud's Pond) up to the time of transfer to salt water. There was one significant deviation, however. In nature, it normally takes about 16 months from spawning for a coho to attain a size of 15 g and go through the process of smoltification. To reduce this period, heat was introduced to the incubators and ponds to accelerate growth. Although the water temperature in Glud's Pond could not be elevated overall more than 1°C, fish congregated in the warmwater plume near the heated discharge pipe, and approached smolt size after only 8–9 months.

2.2 *Saltwater facilities*

Approximately 50% of the juvenile coho (which included the largest fish) were transported in July to floating net pens in Clam Bay, followed by the remainder in early August 1971. Floating net pens in salt water have been the key to Dømsea's salmon culture programme in Puget Sound. They are simply bag nets, supported by flotation, which completely enclose the fish. Free-flowing tidal currents renew dissolved oxygen and flush out metabolic wastes. The nets Dømsea uses are weighted, but have no rigid subsurface structure and yield in the face of currents. Nets have partially collapsed at times, but the reduced volume is compensated by high water exchange. Deep, continuous mixing waters of central Puget Sound act as a thermal buffer, with temperatures remaining between 7° and 14°C the year around. This temperature regime contrasts with that in isolated shallow inlets and diked lagoons where extremes are much more pronounced. The floating net systems are also secured to the bottom using conventional anchors and do not impose permanent changes on the bottom ecology.

The nets used in the pilot programme were fabricated with knotless nylon of 28 kg twine with a stretch mesh measurement of 2·2 cm. Net dimensions were 16 m square and 8 m deep and two nets were situated on each side of a central walkway (Fig. 2). They were supported by floats on the top perimeter and weighted along the bottom perimeter, and the netting was reinforced by polypropylene rib lines. A cover of lighter netting was suspended over each net to discourage bird predation.

The mooring system was designed to hold the complex in a stable position through the use of multiple anchors, counter weights, and wire cable, but the effectiveness of the system was marginal. Anchor dragging was finally prevented by replacing 75 kg anchors with others weighing as much as 2 500 kg. 200 kg counterweights, attached at mid-depth on the mooring cables, were intended to stabilize the complex during 5 m tidal fluctuations but did not prevent the skewing action of strong currents, which resulted in severe strain on the nets.

2.3 *Predation*

Large predatory dogfish, *Squalus acanthias*, which entered one of the nets, chewed large holes through the nylon netting while feeding on dead fish near the footline. Control of this problem was finally achieved by enclosing grower nets with a larger predator net made of nylon gill netting. The space between the grower and predator nets was normally $1\frac{1}{2}$ m, but frequently the two were brought together by currents. Nevertheless, the predator nets were completely successful and no new problems of this nature occurred.

Bird predation exacted a low but continuous attrition of stocks. Overhead nets were partially effective, but they were blown about by the wind and tended to snag as the net complex distorted in the tidal currents. Whenever the protective bird nets slipped away from part of the grower nets, gulls, diving ducks and blue herons preyed on stocks. Adjustment of bird nets to allow access to fish also resulted in excessive time losses.

2.4 *Disease*

Efficient economic use of fish cultivation enclosures requires relatively high fish densities, which in turn result in increased susceptibility to diseases. The gram-negative bacteria, *Vibrio anguillarum* (causing vibrio disease) is endemic in Puget Sound and affects salmonids (Novotny, MS). Each of the large nets in the pilot-phase operation was stocked with about 150 000 young salmon and evidence of vibrio appeared within days of the first transfer to salt water, with chinook salmon being very severely infected. Epizootics of vibrio were controlled by administering terramycin in the feed. It proved worthwhile to treat prophylactically with terramycin before initiating any stressful situation, such as transfer to salt water, seining, or grading. Although outbreaks of vibriosis during the pilot programme were contained, the disease was a chronic problem.

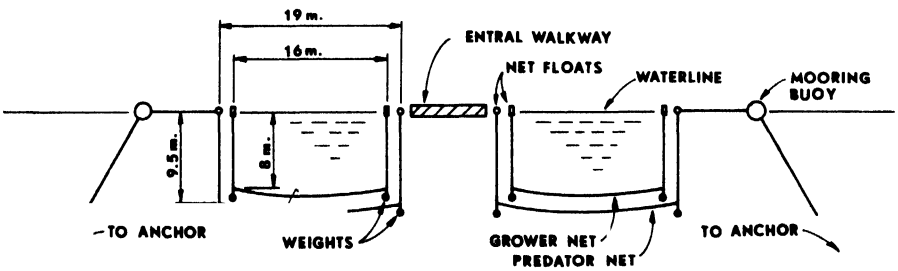


Fig 2. Elevation view of pilot programme floating net complex

2.5 *Feeding*

With 0·5 million 250 g salmon demanding as much as 2½ tons of feed/day, the logistics of maintaining this supply became a significant problem. It was resolved through purchase of a surplus second world war amphibious vehicle (DUKW) to transport feed from the shore to the nets.

In an effort to reduce labour and cost, Oregon moist pellet salmon food was replaced with a dry pellet. Dry pellets are lighter, do not require frozen storage, and are considerably less expensive in terms of cost per unit of protein. The coho salmon accepted dry feed readily and grew at a rate comparable to those on moist feed with a feed conversion ratio of 1·5:1·0 (weight of feed/weight gain). Results with chinook salmon were, however, not as promising. In summer, growth rate and feed conversion with dry pellets were acceptable, but in October their growth slowed drastically and did not resume until the following spring. Reinstituting moist pellet feed to some of the chinook helped, but growth rate was never equal to that of the coho.

2.6 *Chinook salmon*

Chinook proved, in general, to be poorly adapted to net cultivation. They did not grow as rapidly as coho and had lower feed conversion ratios. They were frequently infected by vibrio, which was more difficult to control with chinook than with coho. Scales on smolt and post-smolt chinook are loosely attached and scrape off easily and it proved very difficult to handle chinook without incurring extensive scale losses and resultant high mortality. When chinook were processed for market, it was also found that flesh colour, an important marketing factor, was not as good or as consistent as for coho. Overall, the cost of rearing a kilogramme of chinook to harvest size was higher than for coho, and the resultant product was not as saleable.

2.7 *Results of the pilot programme*

In spite of the various problems, coho grew from 15 g in July 1971 to approximately 300 g by January 1972. Density in the most crowded net reached more than 20 kg/m^3. A harvest weight of about 300 g was selected on the basis of providing consumers with one salmon per serving. The fish were seined out, processed, and tested in a nation-wide marketing programme. Acceptance in the market place was quite good, the only complaint being that the reddish flesh colour was not as pronounced as that in large, wild salmon.

The pilot programme was considered successful. The basic objective of cultivating large numbers of Pacific salmon in high concentrations in floating net pens was achieved. Growth and conversion rates for coho were good and the product, a plate-size salmon, was accepted in the market place.

Regardless of the basic success of the project, several significant problems had not been completely resolved: (*i*) Inventory control was inadequate. There were more fish missing at final harvest than were accounted for by mortality counts. (*ii*) Saltwater facilities were underdesigned, and failures were frequent. The net complex twisted in strong currents, nets ripped, anchors dragged, and cables and lines broke. (*iii*) Significant numbers of the second group of coho, transferred to salt water in August did not smoltify and did not grow until the following spring. (*iv*) Available feeds were adequate, but certainly not ideal for maximum growth and market acceptability of cultured stocks.

3 Commercial programme

Although data for a complete year were not available by late summer 1971, Dømsea elected to proceed with a full-scale production programme to take advantage of the short salmon spawning season later in the year.

3.1 *Site selection*

The site for Dømsea's first production net pen complex was only a few hundred metres from the pilot nets and just north of Orchard Point in Clam Bay (Fig. 1). The Point gave protection from the most severe storm winds, which blow from the south and southwest. Oceanographic parameters, including currents, temperature, salinity and water depth at this site were considered suitable. Orchard Point is the main naval fueling station in north-western United States. Being situated next to the base relieved Dømsea from the need to obtain clearance from beach-front land owners as required by law in Washington State. There was concern at first with the potential danger of oil spillage, but rapid tidal flushing of the area and the good record of the Manchester Fueling Base led to the belief that the risk of dangerous spillage was quite low.

3.2 *Institutional problems*

As a commercial company, Dømsea was faced with the full range of requirements and regulations of local, state, and federal governments. The concept of salmon farming was new and an act of the State legislature was required before commercial salmon farming became legal. Thereafter, a licence had to be secured from the Washington Department of Fisheries and a lease had to be negotiated with the Washington State Department of Natural Resources. Before any floating facilities were installed, a permit was required by the US Army Corps of Engineers; and before the engineers would issue a permit, they had to advertise the application publicly and receive positive clearance from: US Navy; US Department of Commerce; US Environmental Protection Agency; US Department of the Interior;

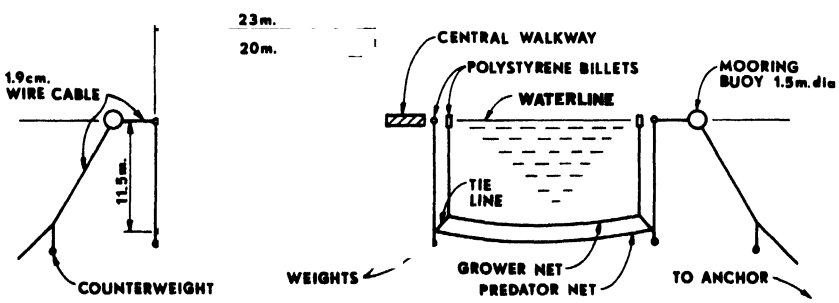


Fig 3. Elevation view of first commercial floating net complex

Washington Department of Fisheries; Washington Department of Ecology; Washington Department of Natural Resources; Washington Parks Department; Washington Department of Health; and finally, the Kitsap County Shorelines' Management Group.

While most of the agencies had legitimate reasons to be involved, many appeared to have overlapping requirements. A considerable amount of time and paper work was involved with these negotiations before final clearance was obtained to proceed with the operation.

3.3 *Design and operation of net complexes*

The generally accepted assumption in the United States that size is directly proportional to efficiency was followed in designing the new net complexes. The next generation grower nets were 20 m square, 10 m deep, and had a theoretical capacity of 250 000 salmon weighing 250 g each. Net strength was reinforced by doubling the twine strength to 57 kg and adding more and stronger criss-crossing rib lines. Each pair of grower nets was enclosed by a predator net 45 × 23 × 11·5 m deep. The predator net was made in similar fashion to the grower net, but of 28 kg twine of a larger mesh size. Both nets were treated with preservative to reduce abrasion. At the bottom end of each vertical rib line on the predator net a 30 kg weight was attached. The grower net was tied to the predator net by lines between the bottom perimeters. The top perimeter of both nets was supported on all sides by a continuous chain of polystyrene billets approximately 35 cm square in cross section.

One set of nets within a confining grid of cables was secured to each side of a central walkway (Fig. 3). The walkway and grids were moored with 14 mooring legs. Each leg, from the grid to the bottom, consisted of 25 m of 1·9 cm diameter galvanized wire cable, a buoy 1·5 m in diameter, 150 m of 1·9 cm cable, and 15 m of 3·8 cm chain terminated by a 1 360 kg danforth-type anchor. The entire complex was maintained in tension throughout the tidal cycle by weights of approximately 200 kg attached 30 m below the buoy. Two such net complexes were fabricated and later extended to a total of 12 nets.

The first new complex was installed in the late spring of 1972. Tidal currents with water velocities up to 1·5 m per second dragged and twisted the vast expanse of netting. Tears appeared, usually at the intersections of rib lines or at the attachment points of weights. Several times, rib lines came loose and whole panels of netting tore free. Floating debris and logs, often embellished with spikes, damaged the top sections of mesh. The long predator nets were replaced with single nets enclosing only one grower net apiece. Strength of grower nets was increased so that the upper 4 m had a twine strength of 115 kg. For the next year these nets, reduced in size and greatly reinforced in strength, held together.

In the summer of 1972, in spite of the problems with nets, extra net space was available in the rearing complex. Consequently, Dømsea negotiated a contract with Washington Department of Fisheries whereby 560 000 coho smolts were given to Dømsea and, in return, the company agreed to release 50% after several months of rearing. Unfortunately, by July only 4 000 of these fish remained; it appears that coho salmon smolt have an overpowering instinct to migrate, and the majority had been able to escape through three small (3 cm diameter) holes near the surface of the net.

Engineering failures occurred again in the autumn of 1973. Moorings were not stable in the face of tidal action and both complexes continuously skewed in the current. Accumulated stress resulted in tears, again at ribline intersections and at weight tie-down points. The skewing was particularly damaging to the overhead bird nets. Five m poles were affixed to floats in the centre of each grower net to keep the bird nets clear of the surface. Skewing, however, broke the securing lines and dropped the nets into the water. Some of these protective nets were gillnets which entangled fish resulting in high mortalities.

A year after nets had been installed in sea water, fouling became a major problem. Algae, tunicates, and similar marine growth reduced water flow, but not to a critical degree. However, the presence of mussels (*Mytilus edulis*) was more serious. A heavy mussel set in 1972 threatened to sink the polystyrene perimeter floats with the heavy weight causing significantly increased current drag and resultant stress to the systems. In attempting to move the nets ashore for cleaning, the force required to lift them caused extensive damage. Some success was obtained through cleaning nets by divers but at great expense of time and effort.

With these accumulated problems, an extra strong tide in June 1975 caused catastrophic failure of the wire cable system with a resultant collision of the two net complexes which resulted in total destruction of the saltwater rearing facilities.

Subsequently, a very simple new net with dimensions of 14 × 5·5 × 5·5 m deep was designed. It was made of 57 kg twine with 2·5 cm stretch mesh. All seams were stitched and there were no head lines, foot lines, or rib lines. Weights were suspended on the inside. With this net design, it was hoped that all major stress points would be eliminated. Cost was also about one third of a net reinforced with lines.

Sixty-four nets were installed within a lattice work of perimeter walkways secured on each side of a 4 m centre walkway (Figs. 4 and 5). All walkways were tied together with cables and held in tension by moorings. This articulated system which is still in use, undulates on the water surface as waves pass through the complex. Each net well is bordered by a wooden railing with pegs on the top which

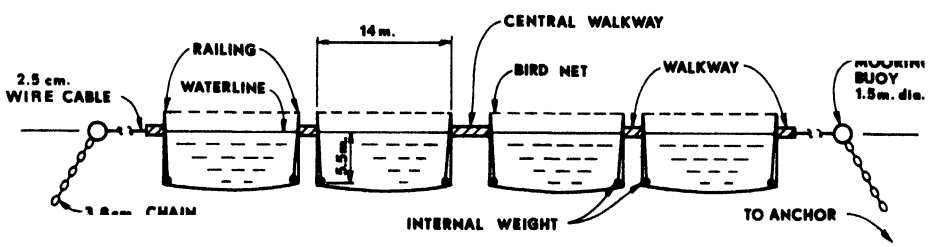


Fig 4. Elevation view of second commercial floating net complex

hold up the net, the weights, and a tightly stretched bird predator net.

The operation of these nets has proved to be very satisfactory. They are easy to install and remove by two men and no diver assistance is required. Dead fish can be removed by an attendant on the perimeter walkway with a long-handled dip net. Dogfish do not seem to attack a small net so predator control nets are not necessary. To harvest fish one end of the net is lifted and the confined fish are pumped out. Marine fouling is controlled by pulling up the net or part of the net and leaving it to dry on the railing. Fouling organisms die and fall off when the net is returned to the water. After a year's operation with 64 nets, there has been no stress damage to the netting. Finally, capital costs are about the same as for the previous system in terms of fish production but labour costs are reduced by about 50%.

The mooring system, failure of which caused the destruction of the previous net complexes, has been significantly reinforced. Wire cables from the walkways to the buoys are 2·5 cm rather than 1·9 cm. Ships' anchor chain with link cross sections of 3·8 cm are used from the buoys to the 1 360 kg anchors. There have been no failures or slippage. An added benefit of heavy chain is that its weight acts as a strong stabilizing influence in the face of tidal action. Little movement can be seen during strong currents and there is no skewing.

3.4 *Effect of incomplete smoltification on growth and survival*

Most of the fish growing in the freshwater facilities did not smoltify completely in 1972. To prevent overcrowding in these facilities, pre-smolts were moved to saltwater facilities in the hope they would smoltify later. This did not occur, however, and high losses were experienced. While perhaps 50% of these fish smoltified the following spring in salt water, their growth was slow and feed conversion was poor. Consequently, there were few fish to sell that winter, promised orders had to be cancelled, and market creditability suffered.

3.5 *Disease*

In midsummer of 1973, 1 800 000 coho salmon were being held in the net complexes and maintaining both the 1971 and 1972 year classes at the same time caused an acute crowding problem. Although four new grower nets were added, the high stocking densities increased susceptibility to disease outbreaks. For some weeks after saltwater entry, there were sporadic outbreaks of *Aeromonas*, a residuum from an epizootic in the freshwater rearing facilities. Subsequently, vibrio outbreaks became frequent. Treatment with antibiotics, primarily terramycin, was successful in eventually controlling each outbreak but at least one group of fish and sometimes all the fish were being medicated from July to November 1973. Medication was expensive and seemed to depress feeding and growth rates. There was also concern that a strain of vibrio would develop resistance to terramycin. Attrition of stocks was chronic and, in some cases, acute with one net containing 135 000 fish sustaining a loss of 60% in three weeks and overall losses attributed to vibrio alone were estimated at 30%. These losses severely affected the economics of the operation and new approaches to this disease problem had to be taken.

Oregon State University was the first to show success in immunizing salmon against *Vibrio anguillarum* by including killed vibrio bacteria in their feed (Fryer, Nelson and Garrison, 1972). Novotny (MS) also injected salmon with

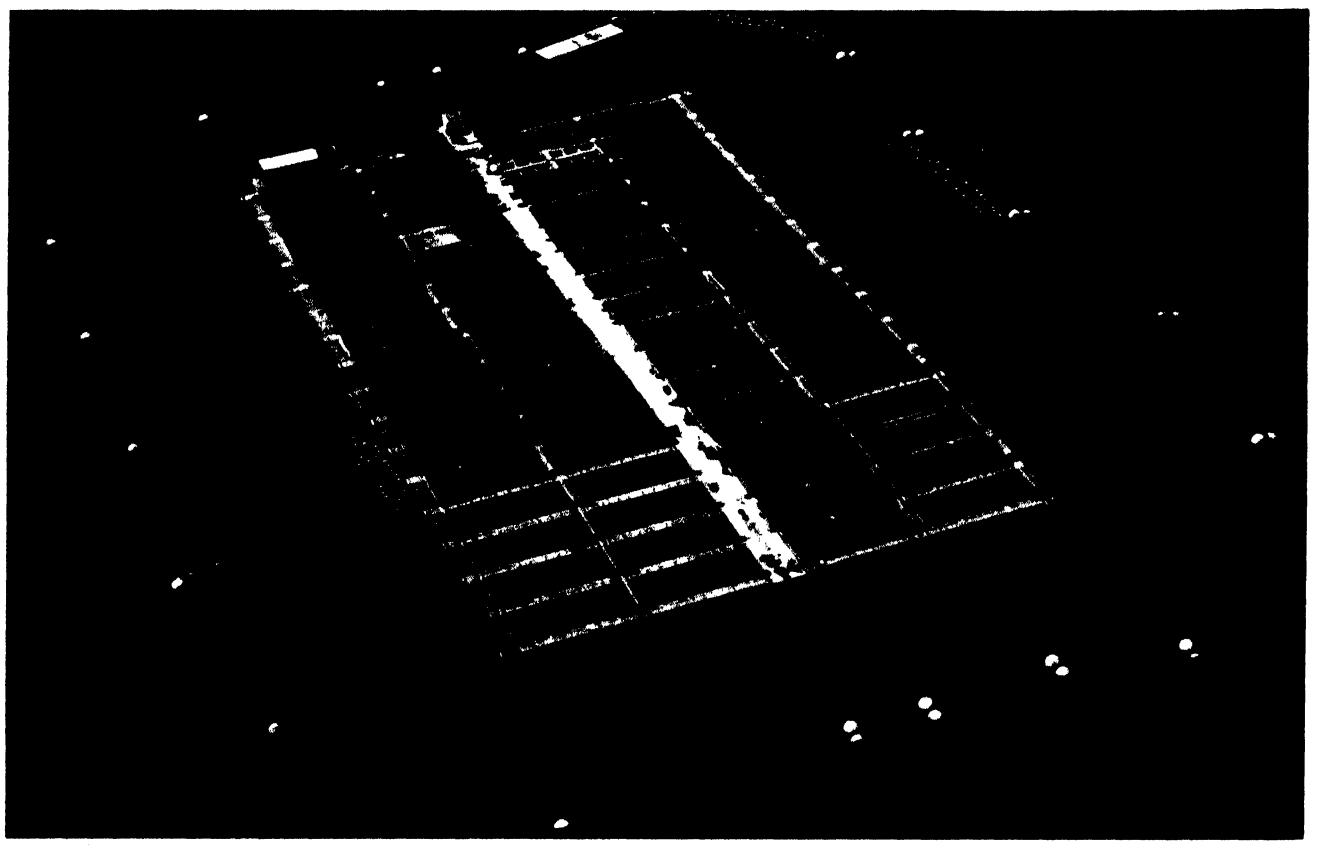


Fig 5. Dømsea Farms, Inc. floating net pen facility in Puget Sound, Washington State, U.S.A. (*photo by US National Marine Fisheries Service*)

Fryer's bacteria before introducing them to salt water to assess this technique of immunization.

These two methods were used in a programme to immunize most of the 1973 year-class coho salmon against two strains of vibrio occurring in Clam Bay (Harrell *et al*, 1976), at a cost for each method of US$ 10·00/1 000 fish. While no final data are available on the success of this immunization programme, losses to date from vibrio have been less than 2%.

3.6 *Efficacy of captive broodstock*

When stocks from the pilot programme were harvested, the largest and fastest growing fish of both coho and chinook salmon were selected as broodstock. They were held in a separate net and fed commercial dry pellets with the carotenoid pigment, canthaxanthin, added. Mortalities for coho, from the time of their selection to sexual maturity ten months later, was about 50%, mostly from kidney disease. Weight of the coho at maturity averaged 2·7 kg which was less than the average weight of wild Skykomish parent stock. The average number of eggs per female coho was almost equal to that of wild females.

No success was obtained with the chinook broodstock programme. Out of several hundred fish selected, only two females reached maturity at age two years and both of these died before viable eggs could be taken. This failure with brood chinook salmon was attributed primarily to deficiencies in the diet, and the programme was terminated.

Eggs from the coho broodstock were stripped, fertilized, and incubated in the project facilities. Sperm from net-reared males was also used to fertilize 590 000 wild eggs purchased from the State. The eggs from Dømsea net-reared 1970 year-class coho were smaller than wild eggs and had less carotenoid pigments, but they were larger and distinctly more pigmented than eggs from NMFS 1969 year-class coho fed with commercial salmon feed without added carotenoid pigments (Novotny, personal communication). Fertility was about 60%, as compared to 70% in a parallel group of wild eggs. The NMFS 1969 year-class eggs had a fertility rate of less than 10%. Work by Buss (personal communication) and others also indicates that canthaxanthin has a marked beneficial effect on fertility of domesticated salmonids.

Fry from Dømsea's domesticated 1970 year-class coho were smaller, and early fry losses were higher than in standard hatcheries. After reaching a weight of one gramme, however, they grew about 10% faster than average fish from wild parents.

3.7 *First commercial harvest*

The first significant harvest of 1971 and 1972 year-class cohos began in November 1973. Fish were confined by seining a grower net and then pumping fish out and across a Nielsen grader. Those larger than 140 g continued into a tank of cold brine (−2°C) where they were killed and cooled to a temperature just above freezing. They were dressed, sorted into 28 g weight increments, sealed in individual plastic pouches, placed in 2·3 kg boxes, and blast frozen. Six boxes were packed into a 11·4 kg case for final marketing.

Six hundred and fifty-five thousand fish were harvested, with a total round weight of 213 000 kg. As each net was emptied, it was invariably found that there were fewer fish than shown in the inventory, but average size was larger than indicated by subsampling techniques. The shortage was attributed to bird predation, tears in nets, escapes over the billets, and uncounted mortalities. The larger average size was attributed to the fact that a higher percentage of the bigger, stronger fish escaped the subsample seine.

4 Present status

It is now believed that Dømsea has overcome the two most serious obstacles to success in the commercial culture of Pacific salmon in floating net pens, namely suitable facilities and control of diseases. Some problems, of course, still remain to be completely resolved (Mahnken, 1976). Less expensive methods of imparting red carotenoid pigment to the flesh to improve health and market acceptability are needed, saltwater nutrition requires further refinement, and further efforts must be made to obtain a higher percentage of coho salmon which smolt in their first summer. However, these problems are not major constraints to continuation of the programme, and in 1976 the Dømsea Farms operation in Clam Bay hopes to 'turn the corner' to become a profitable aquaculture enterprise.

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Recent Developments in Cage and Enclosure Aquaculture in Norway

D. Møller

Abstract

The culture of fish in floating net cages or netted enclosures is a relatively new development. Floating cages, which consist of a floating unit, a framework and a net are in most common use among mariculturists. Sublittoral netted enclosures are more dependent upon locality but can fence in large areas and rear a large number of fish.

The most important factors concerning these devices are discussed: location, topography, various environmental factors (oxygen, currents, pollution, shelter, tides), biological factors (fish behaviour, physiological requirements, *etc*), feeding and handling of fish, mooring, fouling of nets, predation and costs of construction and upkeep.

The construction of three major types of cage/enclosures is described in detail: octagonal cage, a cage system from Bakelittfabrikken, and the Osland enclosures

Développements récents dans l'aquaculture en cages et en enclos en Norvège
Résumé
L'élevage des poissons dans des cages flottantes et dans des enclos en filet est assez récent. Les cages flottantes, comportant un flotteur, un cadre et un filet, sont surtout utilisés parmi les mariculteurs. Les enclos sublittoraux en filet sont plus étroitement liés au site, mais peuvent servir à enclore de vastes superficies et à élever un grand nombre de poissons.

Le document envisage les facteurs les plus importants dont dépendent ces dispositifs: emplacement, topographie, divers facteurs écologiques (oxygène, courants, pollution, abris, marées), des facteurs biologiques (comportement du poisson, besoins physiologiques, *etc*), alimentation et manutention du poisson, mouillage, encrassement des filets, action des prédateurs, ainsi que coûts de construction et d'entretien.

La fabrication des trois principaux types de cage est décrite en détail: la cage octogonale, un système de cage de Bakelittfabrikken et l'enclos Osland.

Progresos recientes de la acuicultura en jaulas y recintos en Noruega
Extracto
El cultivo de peces en jaulas flotantes o en cercos de red es una actividad relativamente nueva. Las jaulas flotantes, que constan de un flotador, un armazón y una red que lo circunda, se utilizan muy comúnmente en maricultura. En el caso de los cercos de red en zonas sublitorales, su dependencia de la localidad es mayor, pero pueden abarcar vastas zonas y en ellos puede criarse gran número de peces.

Se examinan los factores más importantes que hay que tener en cuenta al utilizar estos artefactos: emplazamiento, topografía, diversos factores ambientales (oxigeno, corrientes, contaminacion, protección, mareas), factores biológicos (comportamiento de los peces, necesidades fisiológicas, *etc*), alimentación y manipulación de los peces, amarradero, incrustación de las redes, depredación, y costos de construcción y mantenimiento.

Se describe detalladamente la construcción de tres tipos principales de jaulas/recintos: jaulas octagonales, sistema de jaulas de la Bakelittfabrikken, y recintos Osland.

1 Introduction

There is now increasing interest in farming fish and shellfish in coastal waters due, among other things, to depletion of natural stocks. The culture of fish in floating net cages or netted enclosures in such waters is a relatively new development.

Many of the netted enclosures used in fish farming have already been described (Howard and Kingwell, 1975; Milne, 1972, 1974 and 1974a). Cage and enclosure culture is, however, in rapid development. The aim of this paper is to contribute to that development by providing the most recent information on the subject. After a section on cage and enclosure techniques, the paper discusses in general the most important problems involved in these systems of culture (MacCrimmon, Stewart and Brett, 1974; Webb 1975). The last part of the paper describes three types of pen facilities for fish farming whose specifications have not yet been detailed in international publications (Braaten and Saetre, 1973).

2 The floating net cage

Today most marine fish farmers use floating net cages (Fig. 1) because of their relative adaptability. Culture in cages does not make severe demands on the locality except that it has a certain degree of shelter and opportunity for water-mass exchange. The units can be small or large. They can be moored separately or built together in systems. In addition, floating cages have great variation in form and choice of material. The use of cages is appropriate, therefore, for many different species and for fish farms ranging from the smallest 'hobby pen' to the biggest plant.

A floating net cage commonly consists of a floating unit, a framework and a net. The framework keeps the net apart. Often, however, the framework is simplified and replaced by a rigid floating collar and sinkers.

The floating unit can consist of empty barrels, plastic materials such as Styrofoam, or ready-made pontoons of plastics and metal. The buoy units are often built into a framework which is strong enough to bear a man's weight,

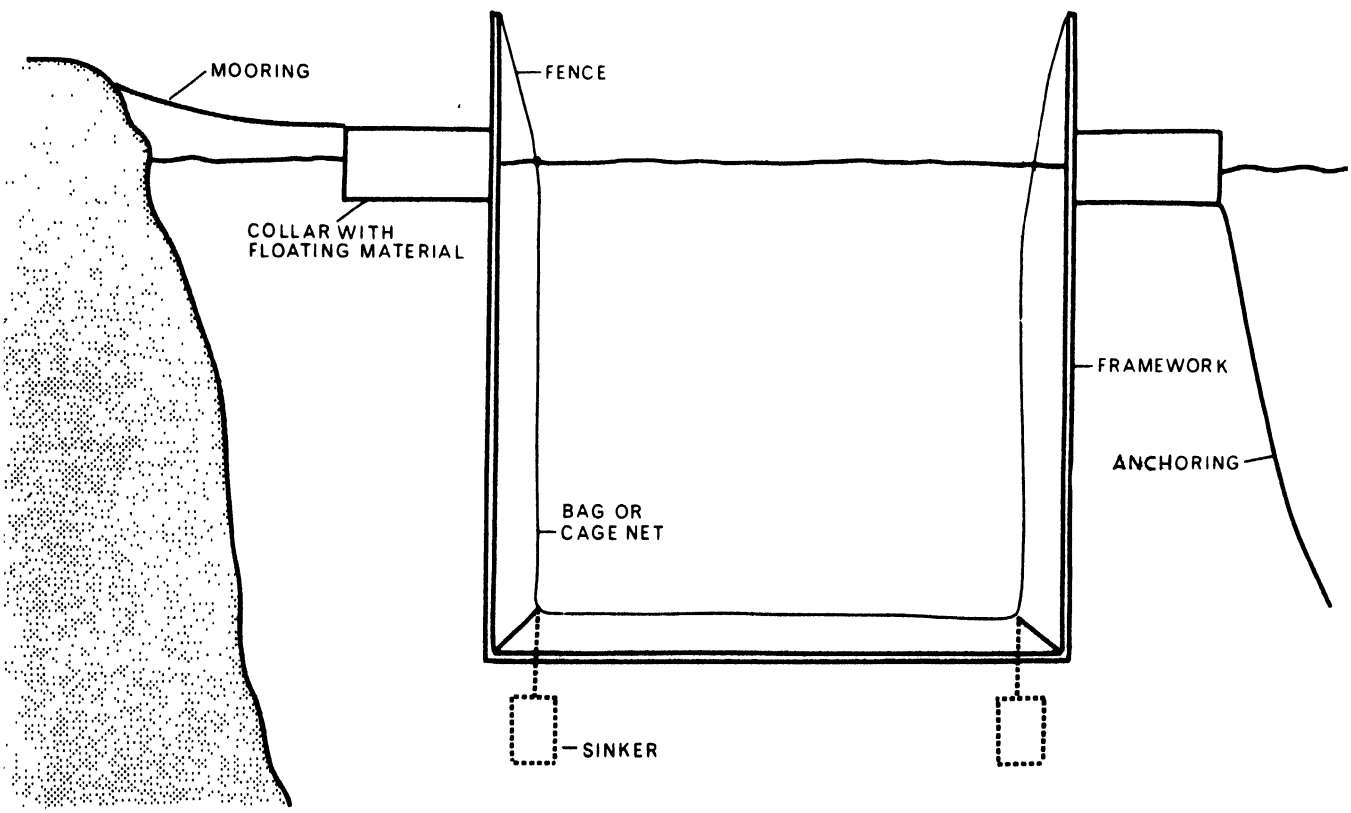


Fig 1. Floating net cage with framework and sinkers

walking or handling fish. However, a cage can also consist of only an unattached bag net tied to four moored buoys.

The material in the framework is impregnated wood, bamboo spars, galvanized scaffolding or welded aluminium bars. Nylon can be used for the net; weldmesh is also used. The mesh is often stretched over frames which, for easy replacement, slide into the general framework.

3 The sublittoral netted enclosure

There is considerable interest among mariculturists concerning the sublittoral netted enclosures, due to the efficient operations of these pens. Each unit can fence in a large area and consequently keep a large number of fish in captivity. Fish feeding and handling can be done easily and independently of a boat. However, these enclosures make certain demands on the locality, especially as to current, the difference between low and high water and shore topography.

Most enclosures are constructed with a framework of timber, steel or concrete piles, or galvanized scaffolding tubes driven firmly into the sea bed. The net can be of nylon, galvanized chainlink mesh or weldmesh stretched over the bars. A special problem is that of escape of fish under the footrope. This is solved by an overlap of netting on the bottom bar, heavy rubble piled on top of the net, or sometimes by providing the entire enclosure with a net bottom. The mode of solution depends upon the bottom structure.

Enclosures are made also with the aid of concrete barriers with steel or aluminium screens. A recent development is a floating fishnet barrier (Milne, 1974a) kept in place by heavy sinkers and equipped with a horizontal floating net to prevent fish escape by jumping.

Most of these fences are constructed along the shoreline, making the shore the longest side of the enclosure. In this way fish farms have been built in bays and sounds.

4 Important factors in cage and enclosure culture

4.1 *Location and topography*

It is most important that a survey of prospective localities for cage or net culture be made before the enterprise is started. A number of fish farms have had to stop production or have operated under heavy difficulties due to environmental factors.

Low levels of oxygen appear to be the reason for low fish growth in some farms. Oxygen consumption depends on the species and amount of fish held, and increases with a rise in temperature and activity of the individual. These demands cannot always be satisfied immediately. Oxygen saturation depends on temperature. In sea water at about 5°C there is more than four times the oxygen available at 20°C. Marine organisms, in particular plankton, also cause variations in oxygen level through their production or consumption of oxygen.

The situation can be especially critical in summer. One of the most important criteria for successful fish rearing is, therefore, the condition of the current. A strong current of about two knots, however, requires a strong cage or enclosure structure to hold the net in place.

Fish farms pollute; the degree is dependent upon the species of fish, their size, feeding ration, *etc.* The magnitude of pollution (feed loss and excrement) from a fish farm using fresh or wet feed may be as much as 60% of the total feed given. More than half of this value represents feed loss. Faeces and food particles sink to the bottom. If the water flow is low and the enclosure bottom bounded by reefs or other thresholds of the main basin, the wastes will accumulate and may contaminate the farm. Small fjords with narrow inlets are not good localities for intensive fish farms above a certain size.

Another important topographical factor is the amount of shelter. Few, if any, structures will withstand the impact of the open sea, but many modern cages or enclosures can bear the winds of an open fjord and waves up to 1·5 m. In cage culture in rough seas it is essential that devices above a certain size move smoothly with the waves. One part of the buoy-supported framework must be able to move down while another part moves up simultaneously. This flexibility can be achieved by using materials such as bamboo or plastic in the framework, or by making the collar of several pieces fastened together by hinges.

In some coastal areas the differences between low and high tide may cause difficulties for fish farming. Due to differences in sea level, it might be impossible to operate with sublittoral enclosures, and the mooring of cages could offer difficulties. These problems can be overcome, however, by attaching the cages to rings (tyres) which have been passed over large piles.

4.2 *Biological factors*

The conditions of captivity for the fish vary according to the biology of the species. Yellowtail (*Seriola quinqueradiata*) and the species of salmonids reared in cages and enclosures today are fast-swimming, pelagic, schooling and predacious. Each species has a unique set of optimum responses. Success in rearing these fish is in part due to satisfaction of their important biological needs.

The biological success of a fish farm, as measured in survival of fish or their growth rate, is highly dependent on the right choice for each species of factors such as: temperature, feeds, feeding strategy, water quality (*eg*, pollution, oxygen content), disturbances and density. Deviations in time and space from the normal or optimal conditions for one or several of these factors will ultimately affect growth and the susceptibility of the fish to disease. Interaction of all these factors makes an extremely complex picture.

Cultivated rainbow trout (*Salmo gairdneri*) are exceptionally insensitive to density and volume. Atlantic salmon (*Salmo salar*) are more dependent on the area accessible to them than to the depth below 3–4 m. These salmon usually swim in circles and are great leapers. Such characteristics reflect behaviour traits which should be considered when planning the construction of cages and enclosures, with respect to their size, area, depth and form.

4.3 *Fish feeding and handling*

Fish feed, its preparation and the feeding itself represent the largest expenditures in a fish farming operation. Many fish farms show a deficit because efficiency in handling of feed has been overlooked. Handling of the feed throughout the fish farm will differ from one farm to another due to factors like types of feed, possible connexions with fish plants or other fish farms, and other factors pertaining to location. Nevertheless, some general advice can be given with respect to feeding in cages and enclosures: (*i*) The number of operations concerned with feed should be as few as possible. (*ii*) In case of wet feed the distance between the feed

processing area and the pens should be as short as possible. (*iii*) The unit amount of fish feed should be as large as possible without losing control of the biomass. (*iv*) A fish farmer should strive toward mechanization. (*v*) If a boat is not used for feeding, pontoon bridges or walkways from land and along the cages may be useful. Walkways will both assist in control of, and provide access to, the net and fish. Fish sorting or sampling, net cleaning and replacement can be done more easily from a rigid walkway collar than from a boat. The collar will both act as protection against drifting logs or debris and, if built strongly enough, facilitate cage removal to another site.

4.4 *Mooring*

The type of mooring selected is dependent on the site. Connexions to the land are preferred to anchoring, but installation of bollards on the land may be expensive.

Heavy concrete block sinkers with chainlink straps to nylon ropes or galvanized wires are commonly used as anchors. Their size depends on the size of the pen, the sea bottom, current and weather. The type of attachment between the pens and the anchor varies from farm to farm.

A few other points deserve consideration. A single cage or enclosure may require more moorings than when it is part of a group, *ie*, a set of moorings can serve several cages. Ropes and wires should be arranged so that they do not hamper access. It should be possible to detach each cage unit easily to facilitate maintenance and repair. Pens should be oriented to the direction of the current.

4.5 *Fouling*

One of the first big problems encountered by fish farmers who use the marine environment for cage and enclosure culture was that of net fouling by algae and mussels. Fouling makes the net heavier, increases the drag in currents and prevents the exchange of water in the pen. Fouling must, therefore, be kept under control.

The immediate environment in a fish farm is always rich in nutrients which accelerate the growth of algae and filter feeders. Water movement diminishes this fertilization, but some of the nutrients can be utilized through polyculture. The introduction of the European oyster (*Ostrea edulis*) in Norwegian fish farms appears to be a good solution, but low temperatures prevent the development of sexually mature individuals.

Materials used for the pens have quite different resistances to fouling. Galvanized weldmesh is better than synthetic fibre, which, in turn, is better than natural fibre (Milne, 1970). An antifouling coating helps and research is underway to find better coatings which do not harm fish.

Since nets must be replaced from time to time, serious consideration must be given with respect to ease of replacement. In some localities the nets are exchanged as many as three or four times a year. In other areas the nets are changed only once a year or every two years. Differences in frequency of changing are in part due to water salinity. Fouling in brackish water does not appear to be as pronounced as in sea water. Another factor of importance is the original level of nutrition in the area.

The time of year chosen for replacement is important. In general, clean nets should be placed in the water after most of the fouling organisms have settled.

Fouled nets are cleaned in several ways. A simple method is to place the net in a solution of copper sulphate (3–4 kg) and formic acid (10–15 l) in fresh water (400 l). Let the net remain there for two to three days, then wash it with cold water using a hose under high pressure.

In addition to the difficulties caused by fouling organisms, shipworms (*Teredo*) bore into untreated wood, and sea water itself corrodes nearly every kind of metal.

4.6 *Predators*

Heavy mortality in enclosures caused by predation has been reported. It has been shown by Møller and Bjerk (1975) that more than half of the total loss of fish has been due to predators. The greatest inroads are on small fish, apparently caused by birds (herons, gulls and cormorants). Predation by larger fish and mammals (seals) has also been reported.

Predatory animals often demonstrate unbelievable cunning in reaching the penned fish, and they acquaint themselves with the protective devices which have been installed. About the only advice that can be given in this regard is to seal off the cages or enclosures completely with nets and wires and to use a shotgun in such a way that birds and mammals avoid the locality. Predatory fish and seals can be kept away with a safety net.

4.7 *Cost*

Cost of production is the most important item in fish culture. Costs may be decreased through better knowledge of nutrition, the ingredients of feeds, and the biology of the cultured organisms. Similarly, investments in cage and enclosure construction may be lessened through attention to the type of materials used and methods of use.

The price varies with materials used. In the construction of framework, for example, the choice can be between aluminium, galvanized iron, plastic or wood; the choice for the net may be aluminium, galvanized weldmesh or synthetic fibre. The investment may also be lessened by selecting materials that can be used by local fishermen, and materials easily obtained locally.

Simplicity in structure should not, however, be at the expense of effectiveness. Ease in operations can repay the investments in terms of lower effort and maintenance of a stable working force. Choice of favourable location will also offer possibilities for increased efficiency of operation.

5 Types of cages/enclosures

5.1 *The octagonal cage*

The floating cage most used in Norway, constructed by fishery adviser Ingar Holberg, is commonly called the octagonal cage. The cage has borne years of wear and tear in exposed localities, and has shown its applicability in Norwegian waters for both rainbow trout and Atlantic salmon culture.

The collar of the cage is octagonal, composed of eight units each 5 m long. The depth of net is approximately 4 m. It has a total volume of 500 m^3. The detailed design is shown in Figs. 2–6.

The units are made of impregnated wood (Figs. 3 and 4). The bearing frame is 2 × 5 inch (51 × 127 mm) plank. The floating units are blocks of styrofoam cut to the size of the frame. Crossbars of 1 × 5 inch (25·4 × 127 mm) planks are nailed to the top and bottom of the frame to keep the floating units in place. The crossbars on top are 3 cm longer than the bottom side crossbars, extending outside the

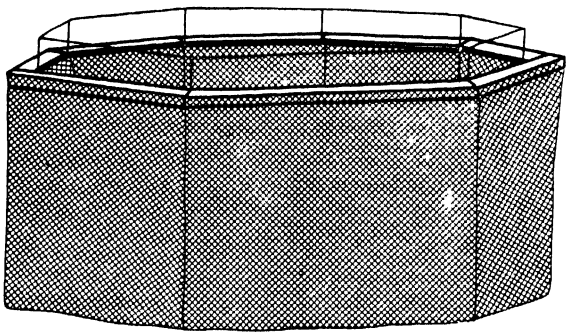


Fig 2. The octagonal cage

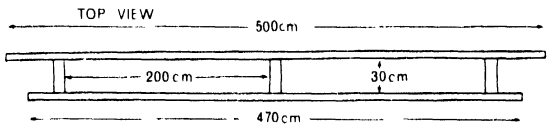


Fig 3. The bearing frame of the octagonal cage unit



Fig 4. The bearing frame of the octagonal cage unit with crossbars

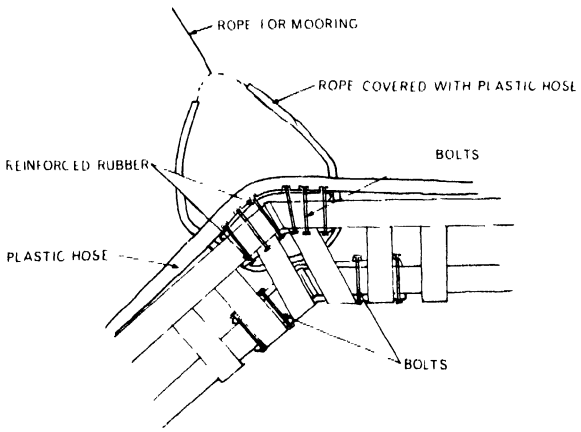


Fig 5. Coupling of units of the octagonal cage

outermost edge of the frame. This is done to hold a 2 × 2 inch (51 × 51 mm) lath used to fasten the net.

The units are held together by reinforced rubber (pieces of conveyor belt or tyres) to make the collar (Fig. 5). Four pieces of rubber are used in each corner, fastened to the planks with $\frac{3}{4} \times 3\frac{1}{2}$ inch (19 × 89 mm) galvanized bolts with washers and nuts. The collar is also reinforced by a wire inside a 2 inch (51 mm) plastic hose nailed around the lower part of the outer side (Figs. 5 and 6). The plastic hose prevents net wear.

For mooring, loops of nylon rope inside a 2 inch (51 mm) plastic hose are threaded through holes in the planks of adjoining units (Fig. 5). The nylon net bag which is made to fit the collar is laced to the lath around the rim and stretched vertically by sinkers.

Inside the collar, four 2 × 2 inch (51 × 51 mm) laths each about 120 cm long are nailed to each of the eight units (Fig. 6). Nylon net is stretched between the laths to act as a barrier against leaping fish. The net should be slack in the corners to allow movements of the collar.

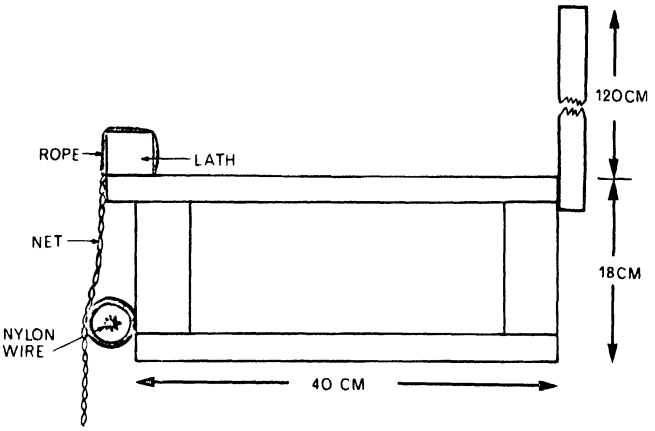


Fig 6. Cross section of unit of the octagonal cage showing attachment of net and lath for the fence

5.2 *Cage system from Bakelittfabrikken*

This system consists of two types of standard elements hinged together (Fig. 7). The elements have the same design but are different lengths, 4 and 5 m. The floating material is PVC pontoons with 250 l buoyancy. Four pontoons, two and two in the same iron frame, are used in each element. The two frames, made of 1 inch (25·4 mm) galvanized iron tubes (Fig. 8) are connected to a wood frame made of 2 × 4 inch (51 × 102 mm) impregnated planks with $\frac{1}{2} \times 6$ inch (12·5 × 152 mm) galvanized bolts with washers and nuts. The wood frame is made in two sizes (4 × 1 m and 5 × 1 m) dependent on the length of the two types of elements. On top the wood frames are covered by 1 × 5 inch (25·4 × 127 mm) impregnated plank.

The elements of the two different lengths are hinged together in such a way that they form a rectangular float with a network of 4 × 4 m square openings. The connexion between elements is shown in detail in Fig. 9. The hinges, all of galvanized iron, consist of 1 m long pivot and fittings bolted to the wooden frame.

The bag net, equipped with a head line and a lead line in the square bottom, is fixed to the rafts with brass hooks screwed into the wooden frame. Fence poles are erected from pedestals; they are easily removed when necessary.

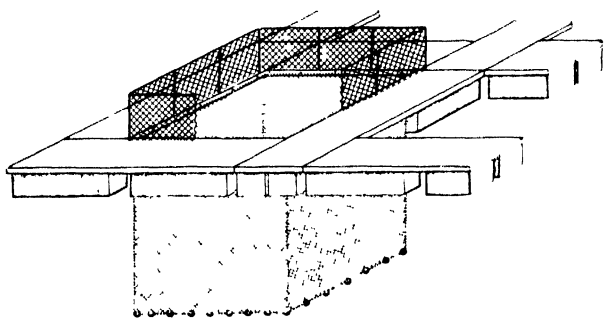


Fig 7. System of cages from Bakelittfabrikken

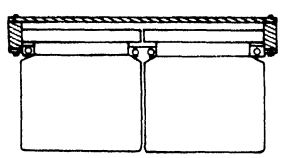


Fig 8. Cross section of element in system of cages

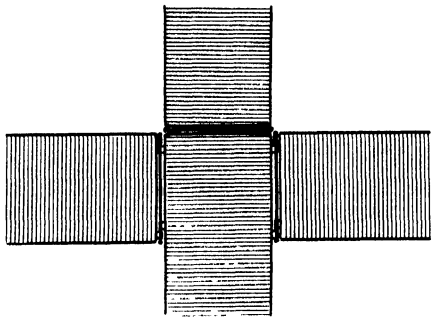


Fig 9. Hinges between elements in system of cages

The size of the cage openings depends on the length of the elements, but it is not recommended that openings larger than 5 × 5 m be used unless another set of hinges is mounted in the middle of the elements. The size of the raft depends on the hinge connexions. The biggest raft measures 33 × 21 m with forty 3 × 3 m holes. Generally, the raft is moored by its four corners. It moves easily with the waves and can be towed.

In spite of the rather complex construction, the cost of this raft is relatively low due to the ease in obtaining its standard elements.

5.3 *The Osland enclosure*

This enclosure is named after its constructor, fish farmer Erling Osland. Its installation requires a sloping shore; about 25 m from the shoreline the depth of the water should be about 10 m.

Concrete or timber dock piles are driven into the sea bed out from the shore forming a square or a horseshoe form of about 25 × 35 m (see Fig. 10). The distance between the piles is about 5 m. The piles must be higher than the water level at spring tide. A concrete wall is built at the shoreline for mooring the net.

Two nets are stretched along the piles; one on the inside to hold the reared fish and one on the outside to ward off driftwood and to keep away predatory fish (Fig. 11). The nets are reinforced by a headline, a midline and a leadline. The headline is connected to the pile with a crossbar, and the midline to the bottom end of the pile. The net between the midline and the leadline, however, lies on the bottom stretched out without any additional hold. In this way the inside and outside nets are attached on each side of the piles, making a barrier for confined fish.

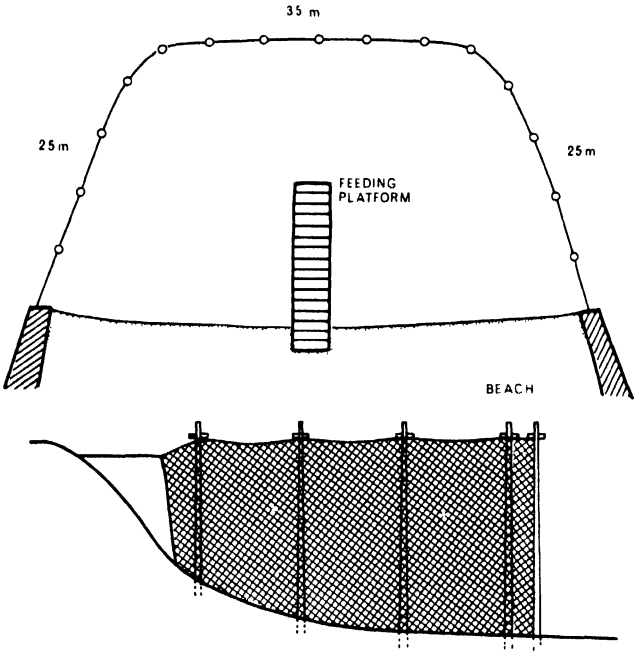


Fig 10. The Osland enclosure

The nets are controlled or exchanged with the help of hauling ropes, which also protect the nets against wear by providing clearance between the piles and nets (Fig. 12). The hauling rope goes through a hole in the crossbar and through a cramp hammered in near the bottom end of the pile. The connexion between the midline and the pile goes over the hauling rope.

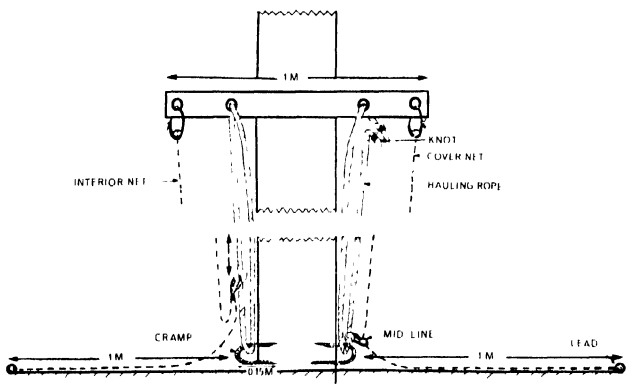


Fig 12. Detail of net attachment of the Osland enclosure

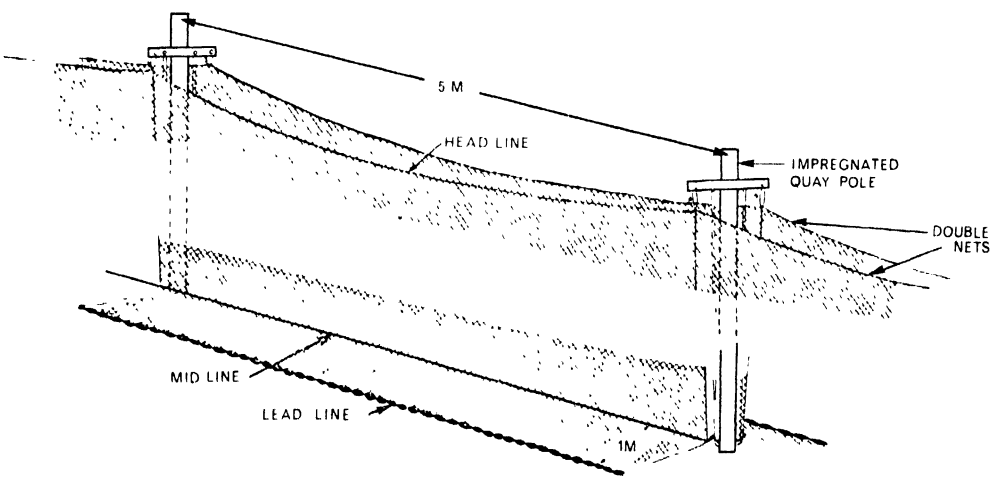


Fig 11. The attachment of net of the Osland enclosure

When the enclosure is in use, the connexion between the midline and the hauling rope is in a low position close to the cramp and the hauling rope is knotted to secure that position. By loosening the knot and hauling the rope the midline with the net can be inspected at the surface.

To facilitate feeding, a platform is built out into the enclosure. Further details of the arrangement are shown in the figures.

6 Conclusions

The octagonal cage is in common use along the Norwegian coast and with respect to practical use and economy it has proved satisfactory for the cultivation of rainbow trout and Atlantic salmon. Preliminary results indicate that the Bakelittfabrikken system and Osland enclosure may attract wide international interest in future. It is hoped that the basic principles of construction and use described in this paper will be useful in the cultivation of marine organisms in other parts of the world.

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Coastal Culture of Yellowtail (*Seriola quinqueradiata*) and Red Seabream (*Pagrus major*) in Japan

M. Fujiya

Abstract

In recent years consumer demand in Japan for marine fish for human consumption has changed. High value products are desired and the demand for food of low value has declined These low-value products, such as sand eel, anchovy and small mackerel can, however, be utilized as food for cultivated marine fish of high value, especially yellowtail (*Seriola quinqueradiata*) and red seabream (*Pagrus major*) File fish, rockfish, puffer, horse mackerel, Pacific salmon and rainbow trout are also cultivable species in Japanese coastal waters.

Yellowtail culture (which accounts for about 95% of the total marine fish cultural production) is described in detail, seasonal routine, seed supply, rearing, types of cages, stocking density, feeding, growth, parasites and diseases and harvest The economics of yellowtail culture is also discussed

Red seabream culture is also described in detail research, seed supply (obtained either through stripping or natural spawning under controlled conditions), hatching, fry rearing, feeding, growth, harvest and release into natural waters.

The outlook is promising for further development of coastal finfish aquaculture in Japan.

Elevage côtier de la sériole (*Seriola quinqueradiata*) et de la daurade japonaise (*Pagrus major*) au Japon

Résumé

Ces dernières années, les demandes de poisson marin destiné à la consommation humaine ont subi des modifications au Japon. On recherche des produits très prisés et la demande alimentaire de produits de faible valeur, a décliné. Ces produits peu prisés (lançons, anchois et petits maquereaux, etc.) peuvent cependant servir à alimenter les poissons marins d'élevage particulièrement prisés comme la sériole (*Seriola quinqueradiata*) et la daurade japonaise (*Pagrus major*). Les alutères, le 'kichiji', le 'fugu', les chinchards, le saumon du Pacifique et la truite arc-en-ciel peuvent également être élevés dans des eaux côtières japonaises.

L'élevage de la sériole (qui entre pour environ 95% dans la production maricole totale) est décrit en détail: habitudes saisonnières, fourniture de semence, élevage, types de cages, densité de l'empoissonnement, alimentation, croissance, parasites, maladies et capture. L'aspect économique de l'élevage de la sériole est également examiné.

On donne aussi de nombreux renseignements sur l'élevage de la daurade japonaise: recherche, fourniture de semence (obtenue par expulsion des oeufs ou par reproduction naturelle dans des conditions contrôlées), éclosion, élevage des alevins, alimentation, croissance, récolte et utilisation pour l'empoissonnement des eaux naturelles.

Les perspectives du développement ultérieur de l'aquaculture des poissons osseux le long des côtes japonaises sont bonnes.

Cultivo de pez limón (*Seriola quinqueradiata*) y besugo (*Pagrus major*) en aguas costeras del Japón

Extracto

En los últimos años ha cambiado en el Japón la demanda de peces de mar para consumo humano: ha aumentado la de productos de alto valor y ha bajado la de alimentos de menor costo. Estos productos baratos, como el lanzón, la anchoa y el verdel, pueden utilizarse como piensos para cultivar peces de mar de mayor costo, especialmente pez limón (*Seriola quinqueradiata*) y besugo (*Pagrus major*). También pueden cultivarse en las aguas costeras del Japón pez ballesta, gallineta, pez globo, caballa, salmón del Pacifico y trucha arcoiris.

Se describe en detalle el cultivo del pez limón (que representa alrededor del 95% de la producción piscicola total en aguas marinas): rutina estacional, suministro de semillas, cría, tipos de jaulas, densidad de siembra, alimentación, crecimiento, parásitos y enfermedades, y recolección. Se examinan además los aspectos económicos del cultivo del pez limón.

Se describe también en detalle el cultivo del besugo: investigaciones, suministro de semillas (obtenidas por desove artificial o por desove natural en condiciones controladas), incubación, cría de alevines, alimentación, crecimiento, y suelta en aguas naturales.

El cultivo de peces propiamente dichos en las aguas costeras del Japón ofrece muy buenas perspectivas de desarrollo ulterior.

1 Introduction

Geographically and historically, utilization of marine products has been most important for the people of Japan.

In recent years, consumer demand for marine products has changed: various high- and middle-value products are now desired while the demand for low-value fish has decreased. These highly ranked products were previously caught mostly from Japanese coastal regions but, as the natural supply is now well below market demand, aquaculture has proved an important means of supplementing the yield from capture fisheries. Consequently, the market values of low-value fishes, such as sand eel, anchovy, small mackerel and others have declined and some species have become considered trash fish. However, use of such fish as feed for more valued cultivated species has restored

demand for low-value fish. Thus, aquaculture, which includes feeding, has a significant meaning in Japan in spite of the world's protein shortage.

Since an aquaculture programme for marine products was first promoted by the Government in the early sixties, production has expanded rapidly to reach 83 800 tons in 1973. The marine species used in aquaculture include yellowtail (*Seriola quinqueradiata*), red seabream (*Pagrus major*), file fish (*Monacanthus cirrhifer*), and rock fish (*Sebasticus marmoratus*).

Production of yellowtail is approximately 95% of the total marine aquacultural fish production, followed by that of red seabream. Yellowtail culture is considered, therefore, to be the most representative type of coastal fish culture in Japan. Consequently, a description of its status and the techniques which are used in its cultivation will occupy the major part of this paper. It will be followed by brief explanations of other types of coastal fish culture in Japan.

2 Yellowtail culture

2.1 *General background*

Yellowtail (*Seriola quinqueradiata*): Adult size in nature: weight 5–8 kg; length 80–100 cm. Market size of cultured fish: weight 1–1·5 kg, and length 30–50 cm in one year; weight 2–3 kg; and length 40–60 cm in two years.

Seasonal routine:

January–August	— Spawning. Water temperature 16–29°C in the southern regions.
April–May	— The larvae are collected from coastal seas. The average size is less than 15 mm (0·1 g).
May–June	— The young are reared to 25–40 mm (0·3–0·5 g) for culture seed.
June–December	— Growing period.
December	— Shipped to market at 1–1·5 kg in weight; or, in a two-year culture operation, shipped to market on demand.

2.2 *Farming procedure*

2.2.1 *Seed supply and rearing.* Although some artificial spawning and larval rearing techniques have succeeded on an experimental scale, an artificial technique for obtaining a supply of seed has not yet been realized commercially. Therefore, seed larvae are collected from natural sources.

A special licence is required to collect and sell larvae in order to avoid overfishing which might cause a decrease in natural stock. Usually, yellowtail 25–40 mm in total length are used as seeds. During early summer, May–June, they migrate to the coast of Japan with the Kuroshio current, usually following floating seaweed, where they are caught by encircling nets. They are kept in small floating net-pens made with fine mesh of synthetic fibre. The net-pens are usually 2–50 m^2 in area and 1–3 m deep.

The most important operation as the first step of seed rearing is the selection by size of at least three grades: large, medium and small. Otherwise, serious cannibalism will occur and mortality up to 50% may frequently result.

The principal food for seed rearing is minced flesh of fish, like sand eel, horse mackerel and shrimp. The choice of species to be used as fish food is an important consideration. White-meated fish with little oil or fat should be suitable and feeding to about 80% satiation is recommended. In some areas, growers feed the fish zooplankton. Lights are suspended above the holding pens at night to attract these organisms through phototaxis.

Seeds sold for stocking in growing cages vary from 5 to 10 cm in total length and 8–50 g in weight but larger size seeds are preferred. Growth to this size usually requires 4–6 weeks in pens.

2.2.2 *Growing for market*

(*i*) Facilities and farming ground

When yellowtail farming first started, three types of growing facilities were used: ponds, netting enclosures, and floating net-cages. The floating net-cage is now the most popular of these.

The siting of the cages is strictly regulated by the prefectural governments and in choosing a cage site, the following factors have to be taken into consideration: (*a*) The farming area has to be protected naturally or by simple construction against violent wind and wave action. (*b*) Tidal and/or current flows have to be sufficient to keep the concentration of dissolved oxygen over 3 ppm and to clean the cages by washing away faeces and uneaten food. (*c*) The water temperature has to be suitable for the species; usually the range for yellowtail is 18–29°C. The optimal temperature range for best growth is 24–29°C. The lower and higher critical temperatures are 9 and 31°C respectively. (*d*) Water salinity has to be above the critical concentration. For best growth, cages should not be sited where the salinity drops below 16 ppt. (*e*) The growing area has to be protected against pollution from agricultural, industrial and domestic wastes. (*f*) The water should be clean from a sanitary point of view.

Two types of cages are used for yellowtail farming: floating and submerged. The basic structure of these two types of cages is shown in Figs. 1 and 2. The ordinary type

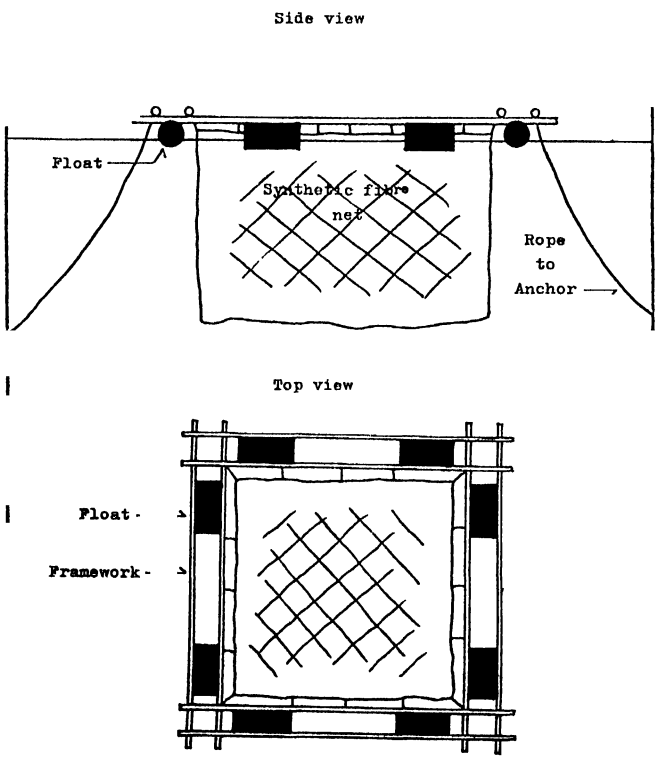


Fig 1. Floating net cage for yellowtail

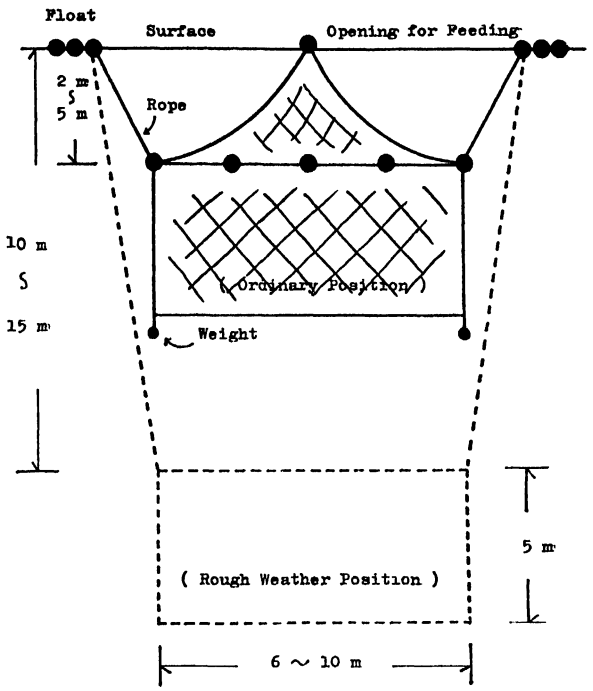


Fig 2. Submerged cage for yellowtail

of floating cage is hung from a framework usually made from bamboo or cedar rods 10–15 cm in diameter or sometimes from steel pipe 3–5 cm in diameter. The framework is buoyed by styrofoam cylinders about the size of a 50 gal drum, usually encased in polyethylene to protect them from barnacles and other fouling organisms. Sites for such cages are limited to areas where damage from wind and waves can be avoided.

A submerged cage which has been developed recently can resist wind and waves much better than the ordinary floating cage and hence is more suitable for open sea areas. Its development has expanded the culture industry considerably. The headrope of the cage is attached to taut mooring ropes suspended from plastic surface buoys. Under calm conditions the mooring ropes are kept short (2–5 m from the surface); in rough weather the ropes are dropped to 10 m or more. In order to maintain the shape of the cage, four weights of about 10 kg each are attached, one at each corner of the cage bottom. If the current is strong, additional weights are applied. Ten to twelve cages are usually grouped as a unit. A 'feeding passage' is connected to the top of the net. At feeding time, the upper end of the passage is raised to the surface and the stocked fish are fed through it.

(*ii*) Stock density in cages

After the seeds are ready, they are transported to the farming facilities. When the seed size is 5–10 cm in total length, standard stocking densities are as follows: 80–200 fish/m^3 in a cage; 5–20 fish/m^3 in a net enclosure; and 1–2 fish/m^3 in an embanked enclosure.

In the case of a floating cage, the density of stock in the cage is especially important. See Table I for the recommended relationship between density and cage size.

(*iii*) Feeding procedure

Feeding is crucial in growing yellowtail for market; 40–70% of the budget of the average grower is spent for food. The most suitable food for yellowtail is white-meated fish, such as sand eel, horse mackerel or saury; anchovy is also commonly fed.

With the decrease in demand for low-value fish (mentioned in section 1), the market value of sand eel and anchovy has declined and these species have become regarded as trash fish. With increased demand for yellowtail as food, however, the catching of such low-value fishes has been resumed. Thus, feeding culture still has a significance in spite of protein shortage.

The continuous feeding of anchovy sometimes causes high mortality because of oxidation of the unsaturated fatty acids in anchovy flesh. The oxide or peroxide compounds are harmful to fish but special supplements and mixed feeding with other fish meat can avoid the problem. Thiaminase in anchovy flesh meat destroys vitamin B_1 in yellowtail and also results in high mortality.

Artificial diets for yellowtail are available but are not commonly used by commercial growers. The most suitable diet consists of at least 70% white fish meal with 5–10% gluten as a binder. Other ingredients include vitamin mix, minerals (especially iron and cobalt) to prevent anaemia, and sometimes the enzyme protease. Growth obtained with this diet is not sufficient in comparison with that attained with fresh fish but if the two kinds of foods are alternated the growth is better than if fresh fish alone is fed. Wide adoption of such a diet is retarded at present by its high cost.

Considerable effort has been expended in determining the proper feeding procedure. The optimal feeding regime consists of two feedings daily: in the morning and in the afternoon. The amount to be fed is dependent upon the circumstances; see Table II for recommendations for optimal feeding rates.

TABLE I
RECOMMENDED YELLOWTAIL STOCKING DENSITY IN CAGES

Size of fish (g)	*Density (fish/m^3)*		*Total number of fish per cage*[1]				
	Weight (kg)	*Number*	*I*	*II*	*III*	*IV*	*V*
10	0·9	90	2 400	8 100			
50	3	60	1 600	5 400	9 400		
100	5	50	1 300	4 500	7 800	10 000	
200	7	35	900	3 100	5 500	7 500	13 000
400	10	25		2 200	3 900	5 400	9 300
500	11	22		2 000	3 400	4 700	8 200
700	10	14		1 200	2 200	3 000	5 200
900	10	11		1 000	1 700	2 300	4 100
1 000	10	10		900	1 500	2 100	3 700

[1] Size of cage: I = 3·0 × 3·0 × 3·0 m; II = 4·5 × 4·5 × 4·5 m; III = 5·4 × 5·4 × 5·4 m; IV = 6·0 × 6·0 × 6·0 m; V = 7·2 × 7·2 × 7·2 m

TABLE II
FEEDING RATE OF YELLOWTAIL

Body weight (*g*)	*Water temperature* (°C)	*Daily feeding rate*[1] (%)
10– 50	15–22	40–60
50– 100	18–24	30–50
100– 200	20–25	20–30
200– 400	23–26	15–20
400– 600	25–28	11–15
600– 800	24–28	9–11
800–1 000	18–25	8–10
1 000–1 200	13–20	6– 8

[1] Daily feeding rate = F/W × 100
F = Amount of food/day
W = Weight of fish

(*iv*) Growth rate

The growth of yellowtail in net cages is remarkably rapid. Generally, seeds of 7–60 g are put into the growing cages in May or June. They grow to 200–700 g by August, 600–1 600 g by October and 700–2 000 g by the end of December. They are then generally harvested and shipped to market. A few fish, about 5%, are left in the cages for several more months, usually until the beginning of next farming season for two-year farming. They are then marketed as 40–60 cm fish weighing 2–3·5 kg. However, two-year farming is carried on only in southern Japan, where the water temperature is suitable for wintering.

2.3 *Parasites and diseases*

Parasite and disease control is a significant factor in yellowtail farming. With expansion of fish farming, fish disease has become a serious problem. The important diseases in yellowtail farming are:

Bacterial diseases

Vibriosis	Pseudomonas disease
Pseudo-tuberculosis	*Ichthyophonus*
Nocardia infection	

Parasites

Myxosporidia	*Heteraxine* (*Axine*) (trematode)
Benedenia (trematode)	*Caligus* (copepod)

Chemotherapy by oral administration of sulpha drugs or antibiotics is effective in treating bacterial diseases but methods of early diagnosis will have to be developed for better control of infection. With respect to parasites, effective prevention and treatment is to bathe stock fish in chemical solution.

Diseases caused by nutritional conditions are also frequently observed. These usually do not cause serious damage but sometimes they trigger the onset of serious diseases.

2.4 *Harvest and economics*

Although the yellowtail harvest season starts in August, market demand is not large at this time because of the fish's small size, *ie*, 300 g or less in total weight. The peak of the harvest is from October till end of December when the size of fish is 1·0–1·2 kg.

Although it is necessary to use fishing gear to harvest yellowtail from enclosure-type farms, only simple equipment such as a dip net is necessary in floating cage farming. This is one of the main reasons for the expansion of the floating cage technique among yellowtail growers. The product is transported to the market by boat or truck mostly in live condition. Otherwise, fish are pithed immediately after harvest to keep their fresh quality.

The economics of yellowtail farming is dependent upon the method used, location and circumstances. Feed is the most costly item. The development of reasonably priced feeds is required for future expansion as the market value of yellowtail cannot be expected to increase.

The average production of a family size grower is 10 000–20 000 fish each weighing 1·0–1·5 kg. A middle class income can be assured with yellowtail farming in Japan.

3 Red seabream culture

Red seabream or red porgy (*Pagrus major*) is a specially categorized fish treated traditionally in Japan as a symbol of auspice and fortune. Thus, it is not only a food but a feature in celebration and especially valued in comparison with other fishes.

Research on farming of this species had been carried out since 1887 and research on its artificial propagation since 1902 without successful results. In 1958, research into its propagation began again using modern facilities and equipment with success attained on an experimental scale in 1962. Since then, red seabream farming has advanced rapidly and is becoming a valuable asset in the development of coastal aquaculture.

3.1 *Farming procedure*

3.1.1 *Seed supply and rearing.* The entire cycle from breeders through egg, larva, seed, growth stages, harvest, and back to breeders again is shown on page 457.

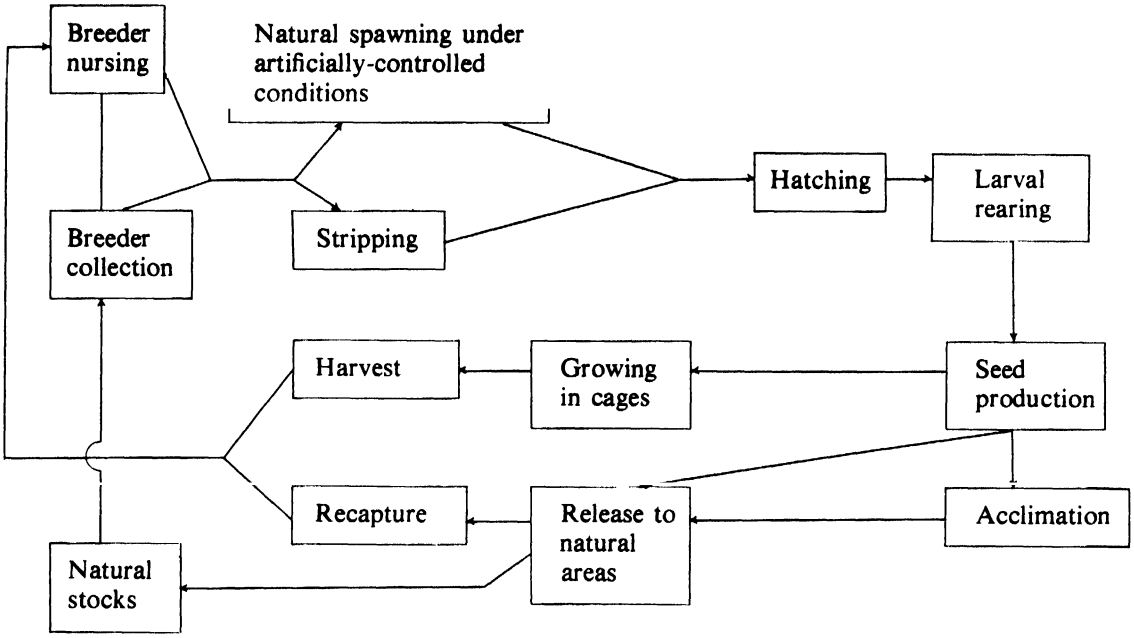
The adults of both sexes are easily distinguishable. Normally, the fecundity of a four-year-old (approximately 1 kg) is 300 000 eggs. Two methods are used to obtain fertilized eggs. In the first of these, eggs and sperm are obtained from wild stock by stripping mature fish immediately after landing by a commercial fishing vessel. A mature egg is about 1·2 mm in diameter and has an oil globule about 0·25 mm in diameter. The surface of the egg is covered by a sticky material which is uncovered when the egg is soaked in sea water. The specific gravity of the egg is about 1·0245 in water of 15°C and should float in sea water of normal salinity. Fertilized eggs are sensitive to fluctuations in temperature and to bright light and must be transported carefully to avoid physical shock. Otherwise, abnormal cleavage may occur.

Under an alternative method, equal numbers of male and female breeders are raised in tanks where they spawn naturally. Spawning continues for several days generally at sunset. The fertilized eggs are collected through siphons or overflow installations. They are then hatched in the same way as stripped eggs.

The environmental requisites for spawning are as follows:

water temperature: 15–22°C (optimal range: 15–21°C)
specific gravity of sea water should not exceed 1·02
sufficient dissolved oxygen.

Hatching time which is related to water temperature is about 60 h at 15°C or 40 h at 18°C. Development stops at a water temperature below 10°C. The zygotes are pelagic



but in sea water with specific gravity below 1·023, they sink to the bottom and have a poor hatching rate.

Following hatching, the fry are inactive for a day and then become active. At this stage, they are transferred to a rearing tank filled with 'green sea water'. Green sea water is usually prepared by filling an outdoor tank with fresh clean sea water to which fertilizer is added at the rate of 500 g/ton of water. The tank is then inoculated with phytoplankton. Within 10 days, the green sea water is ready for fry rearing. Many species of phytoplankters and zooplankters can be found in this water and some are quite suitable as the food for this developmental stage. A plastic container of about $\frac{1}{2}$–1 ton capacity is a suitable tank, and fry can be accommodated here at a density of 40 000 fry/ton of water.

A few days after their introduction, the water should be refreshed gradually with fresh sea water and, after this time, feeding is required. The swimming stage of oyster larvae and zooplankters, such as rotifers are used. About 10 days after hatching, the fry become quite active. The nauplii of brine shrimp (*Artemia salina*) can now be fed and wild copepods can also be used as food at this stage.

During the fry-rearing stage, water quality control is most important. Dead eggs, fish and food organisms must be removed from the tank as soon as possible. Some biological treatment, such as placing small crabs, hermit crab or other shellfish in the tank, may be effective in keeping the water clean.

The egg of the red seabream has an oil globule which has several black pigments; the number of these pigments changes with fluctuation in light intensity. It appears that the oil globule acts as a control of light penetration. It is considered that the range of light intensity permitted into the egg by the pigments is roughly 100–3 000 lux. Thus, the hatching tanks require illumination with a maximum intensity of 3 000 lux at the water surface. The larvae also require suitable light but these requirements fluctuate according to the individual and its growth stage. It is recommended, therefore, that the rearing tank should have several zones of different light intensity ranging between 0 lux and 2 000 lux so that the larvae can choose the most suitable.

When the seabream's length exceeds 20 mm, minced shrimp or fish can be fed to them. The fry can now be transferred to the growing facilities and are ready as seedlings.

3.1.2 *Growing for market.* In intensive farming, seabream are usually kept in a floating cage. The cage consists of a wood or steel pipe framework and a synthetic fibre net. In shape and size, it is similar to a yellowtail cage.

Around August, fry are accommodated in floating cages at a density of 6–8 kg/m^3 of water volume where they are fed frozen fish, such as anchovy and sand eel. An artificial diet which is now available is becoming popular among growers but is more costly than the trash fish diet. Seabream reach market size in 12–18 months.

An extensive type of farming is also practised. In this case, the fry are kept in floating cages or net enclosures for acclimation for several weeks until they are about 5–7 cm long. These juveniles are then released into the sea where natural productivity is utilized for their growth. The suitability of coastal environmental conditions is determined before this release.

Some of the released fish will be caught commercially and some of them should aid in restoration of the natural stock and increased recruitment. In order to obtain successful results it may be useful to improve environmental conditions in the areas of release, *eg*, by providing shelters of concrete blocks or artificial (plastic) seaweeds.

4 Other species cultured

In addition to yellowtail and red seabream, several other fishes are cultured both intensively and extensively in Japanese coastal waters, but their production is much lower. Production of puffer (*Fugu rubripes*) reached 600 tons/year during 1959–61 along the coasts of the inland sea but decreased to a level of only 10–20 tons/year because of increased catch in the capture fishery and a rise in the amount imported.

Horse mackerel (*Trachurus japonicus*) farming is increasing and the farming of file fish (*Monocanthus cirrhifer*) is also growing.

With respect to future development, research on tuna culture has been carried out for a number of years, concerned primarily with determining methods to rear larvae, young and adults. The establishment of complete techniques for artificial propagation, growing and breeder nursing is expected, and some successful results have been obtained.

Experiments have been conducted to develop a technology of Pacific Chum salmon (*Oncorhynchus keta*) culture in the sea and commercial operation of rainbow trout (*Salmo gairdneri*) farming was started in 1968. An annual production of 200 000–300 000 tons/year of fish weighing about 2 kg each is now possible.

Several other fishes are now being considered as candidates for Japanese marine farming.

5 Acknowledgements

The author gratefully acknowledges the co-operation of the Association of Marine Fish Culture and the Kochi Prefectural Fisheries Experimental Station in providing information used in this paper.

Design of Floating Breakwaters

J. Kato, T. Noma and Y. Uekita

Abstract

There is increasing use of offshore installations for aquaculture such as cages for fish and various types of rafts and hanging structures for molluscs. The development of suitable offshore floating breakwaters has become necessary because of the need to extend this type of aquaculture to the open seas.

Through the use of a wave tank (6 × 1 8 × 20 m deep) and models of different forms of floating breakwaters, studies were made to determine the practical application of structures for dissipating wave action during strong winds. This information is essential in all fields of marine development.

The general nature of the damping effect obtained by a double-spaced barrier and the 'absorber mattress' (an example of flexible-type floats) are described. The double-spaced barrier gave excellent damping effect because of phase difference between waves and the barrier (as is the case with floating pontoons) The absorber mattress operates on a different damping mechanism (friction) to the barrier, but also gives excellent damping effects

The damping effect of a float on waves can be obtained by two damping mechanisms, *ie*, reflection and friction It is, therefore, advocated that these damping mechanisms can be usefully employed through combining a rigid or unsuitable float system (barrier types, such as pontoons) and a flexible floating system into one structure which has a composite damping action.

Mise au point de brise-lames flottants

Résumé

L'on utilise de plus en plus des installations situées au large des côtes marines pour l'aquaculture comme par exemple des cages pour les poissons et divers modèles de radeaux et de structures verticales pour les mollusques. Le développement de brise-lames flottants adapté aux conditions existant au large s'est averé nécessaire dû à la nécessité d'étendre ce type d'aquaculture a ce milieu.

On a effectué des études pour déterminer les effets pratiques des structures destinées à dissiper l'énergie des vagues en cas de gros vent. On a utilisé à cette fin un bassin à houle (6 × 1,8 × 20 m de profondeur) ainsi que différents modeles de brise-lames flottants.

On décrit la nature générale de l'effet d'amortissement obtenu par une barrière à double espacement et par un 'matelas d'absorption' (type de flotteurs souples). La barrière à double espacement s'est révélée un excellent amortisseur par suite de la différence de phases entre vagues et barrière (comme dans le cas des pontons flottants) Le matelas d'absorption fonctionne selon un principe différent (friction) mais donne aussi d'excellents effets d'amortissement.

L'effet d'amortissement d'une structure flottante sur les vagues peut être obtenu par deux procédés: réflexion et friction. On estime qu'il serait possible d'utiliser avantageusement ceux-ci en associant un système de flotteurs rigides ou peu satisfaisants (types de barrières tels que pontons) et un système flottant souple, combinés en une seule structure qui exerce une action composite d'amortissement.

Diseños de rompeolas flotantes

Extracto

Hay un aumento en el uso de instalaciones en alta mar, tales como cajas para peces y varios tipos de balsas y estructuras colgantes para moluscos. El desarrollo adecuado de rompeolas flotantes en alta mar se ha hecho necesario debido a la necesidad de extender este tipo de acuicultura a mar abierto.

En un tanque simulador de olas (6 × 1,8 × 20 m de profundidad) y utilizando modelos de diversos tipos de rompeolas flotantes, se han hecho algunos estudios para determinar la aplicación práctica de esas estructuras para disipar la acción de las olas cuando se alzan vientos fuertes. Se trata de información esencial para todos los sectores de actividades marítimas.

Se describe el carácter general del efecto amortiguador conseguido con una barrera doble y con un 'colchón de absorción' (ejemplo de flotador de tipo flexible). Con la barrera doble se obtuvieron excelentes efectos de amortiguación, gracias a la diferencia de fase entre las olas y la barrera (como sucede con los pontones flotantes). El colchón de absorción actúa según un procedimiento de amortiguación diferente (fricción) del de la barrera, pero da también excelentes efectos de amortiguación.

El efecto amortiguador sobre las olas de una estructura flotante puede deberse a dos tipos de acción: reflexión y fricción. Se aboga, por tanto, que en el empleo de estos sistemas de amortiguación puede ser útil el combinar en una única estructura un elemento flotante rígido o no flexible (tipo barrera, como los pontones) y un elemento flotante flexible, la cual tendrá una acción amortiguadora compuesta.

1 Introduction

The development of cage culture for finfish and various types of hanging culture systems for molluscs has led to competition for space in the areas with suitable environmental conditions, *eg* unpolluted water with good nutrient supply, protection from severe wave action, *etc.*

There is now a tendency to move many such aquaculture systems to, or install new ones in, offshore areas where water of better quality can be found and where the installations will not be in severe competition with other water-users. Damage through wave action to the aquaculture systems, as well as interference with routine maintenance work and harvesting are serious problems faced in the use of offshore waters for such forms of culture. Consequently, the development of suitable floating breakwaters which will protect such aquaculture systems is of great importance.

The studies described below were aimed at assessing practical application of structures for dissipation of waves during strong winds as safety measures, which are essential in all fields of marine development.

The action of dissipating incident waves by means of a float, *ie*, the action of a float to dampen and absorb wave energy, mainly consists of either reflection or friction. In a strict sense, both reflection and friction are involved in this action, but one of the actions is more predominant than the other. Generally speaking, it is intuitively considered that reflection is more predominant than friction, and many floating breakwaters which have been conceived were tacitly based on the expectation of utilizing the damping effect by reflection. In such cases, however, the motion of the float caused by incident waves was not given sufficiently careful consideration. For instance, to obtain a damping effect, painstaking efforts were made to prevent the float, as far as possible, from being rocked by incident waves. As a result, when the float system (a float and a mooring system) was constructed on a practical scale, it did not demonstrate the

expected damping effect. Sometimes the float synchronized its motion with that of incident waves (*ie*, the float rode on the waves) and was unable to dissipate the wave height sufficiently.

It can, therefore, be stated in general that the damping function of the floating breakwater is greatly dependent upon the damping mechanism (reflection in this case).

However, Kato *et al* (1969) demonstrated that an excellent damping effect could be obtained by causing the motion period of incident waves to shift from that of the float, *ie*, by utilizing the phase difference, and postulated that the vital point in the future development of floating breakwaters based on reflection lies in utilizing the phase difference.

Later, the authors selected typical floats of various shapes excluding the pontoon, and repeated experiments with them to determine their damping effect. In the case of the pontoon, excellent damping was obtained by utilizing the mechanism of phase difference, but difficulty occurred in anchoring the float securely, because the mooring rope and the sides of the float developed strong stresses. Consequently, experiments were conducted on simpler floats such as a 'board' and a float, which was made by fitting a perpendicular wall at the end of its horizontal board. However, these floats did not give sufficient damping effect when they were made on a practical scale. Then an experiment was made on the double-spaced barrier. This float was effective in eliminating the difficulties of the pontoon, indicating its potential as a practical float.

All the floats mentioned above operate on reflection as the main damping mechanism, and at the same time are not deformed by incident waves. Flexible floats which rely on friction were then taken into consideration. The simplest form of this kind of float was a sheet. Wiegel (1962) conducted experiments on the sheet; the results showed that in order to obtain practical damping effect, it was necessary for the sheet width to be more than ten times the length of incident waves. However, even in the case of flexible floats, the benefit of shifting the motion period of the float from that of incident waves (*ie*, causing the phase to shift) can be taken into consideration. The authors repeated the experiments on a sheet which was given density difference, or on a sheet from which weights were suspended. As a result, fairly satisfactory damping effect was obtained in experiments carried out in an experimental water tank. However, since the analogous relationship between the conditions in the experimental tank and those in the field was not clear, more experiments had to be carried out for the purpose of practical application. In addition, the shape of the float was too complicated to make it a suitable marine structure. Consequently, experiments were carried out on a spherical float from which weights were suspended, namely, a typical flexible float having a pontoon; it was found that such a float also had the same defects as the plain sheet and was still unsatisfactory for development for practical application.

Therefore, consideration was given to a float structure in which damping effect could be obtained by friction alone, neglecting reflection for the time being. The structure used was an absorber mattress, and satisfactory results were obtained from this kind of float.

Through these various experiments, the authors were able to determine generally the nature of the damping effects of all floats from the viewpoints of damping functions and damping mechanisms. If it were possible to obtain sufficient damping effect for practical application by a single float and to design a structure which would not cause the float anchoring device to generate too much tension or stress (by incident waves), such a float would have practical use as a floating breakwater. However, it was found that it was impossible to develop a practical floating breakwater by means of a single float, and it was considered that a combination of floats of more than two kinds, namely, a float that combines different damping mechanisms, was required for developing a practical floating breakwater. For this purpose, consideration was given to the 'double-spaced barrier', one of the simplest forms utilizing the phase difference, and to the 'mattress' which relies on friction as its main mechanism. These two types will be fully described, and the possible shape of a practical float will be suggested by limiting practical design conditions.

Floats can be classified as shown in Table I according to their damping effect.

TABLE I
WAVE DAMPING FUNCTIONS OF FLOATS

Name	*Kind*	*Max damping effect in laboratory* %	*Advantage*	*Disadvantage*	*Damping mechanism*
A Rigid or immutable float	(1) Pontoon	Nearly 100	Damping effect is the largest and designing according to theory is possible	Tension applied to mooring device is large, and construction cost is comparatively high	Phase-difference reflection
	(2) Others	80	Damping effect is smaller and reasonable designing is possible.	Scope of design conditions within which large damping effect can be obtained is narrow.	Phase-difference reflection
B. Flexible float	(1) Sheet	40	Tension applied to mooring cable is small.	Choice of materials and execution of methods is difficult.	Phase-difference reflection and friction
	(2) Float having characteristics of both A and B.	70	Tension applied to mooring cable is small. Construction cost is smaller than that for A.		Phase-difference reflection and friction
	(3) Sheet-like mattress	80	Tension applied to mooring cable is comparatively small. Construction cost is smaller than that for A.		Friction

The following are the symbols used in this paper:

H_0 = Height of incident waves
L_0 = Length of incident waves
H_T = Height of transmission waves
H_0/L_0 = Wave steepness
h = Depth of water
T = Rolling period of float (rotary motion in the plane parallel with the travelling direction of waves)
T_W = Wave period
a = Board interval of perpendicular-board float
l = Length of mooring cable
t = Thickness of mattress
d = Distance from still water surface to bottom line of float
E_W = Kinetic energy of incident waves
P = Density of water
l_o = Length of mattress
t_1 = Thickness of mattress above water level
α = Coefficient of friction
h_d = Height of perpendicular board of float
h_w = Draft
E = Kinetic energy of waves contained in the water column from water level to water bottom per unit area
E_d = Kinetic energy of water from water level to the centre of weight

2 Floating double-spaced barrier

Even though the barrier-type float is slightly inferior in its damping function compared to the pontoon, it is considered here because smaller load and smaller tension are applied by waves to the float and the anchor rope of a barrier-type float compared to a pontoon-type float.

2.1 *Experimental procedure*

2.1.1 *Wave tank.* The wave tank was a concrete structure measuring 21·6 m × 1·8 m × 20 m deep. On one side of the tank, two glazed observation windows each 4·0 m long were provided. At one end of this tank, a flap-type wave generator (5 PS) was installed. At both ends of the tank, wave dampers were fitted to prevent reflection.

2.1.2 *Model waves.* Model waves used for the experiment had the following ranges of specifications: Wave height H_0 = 5–25 cm; wave length L_0 = 0·8–3·80 m; and wave steepness H_0/L_0 = 0·015–0·110. For measuring wave forms, a resistance-wire wave gauge and an electromagnetic oscillograph were used in combination. Measuring locations were at three positions in front (sea side) and two positions in the rear (land side).

2.1.3 *Models.* The model consisted of two wooden boards having a thickness t = 5·0 cm, fixed and connected by four iron bars into a single body. The interval between the two boards of three models were set to 0·50 m, 1·00 m and 1·50 m, respectively. In each case, provision was made for enabling the relative depth h_w/h_d (= ratio of draft h_w to barrier height h_d) to be: $\frac{1}{4}$ (0·125 m), $\frac{1}{2}$ (0·25 m) and $\frac{3}{4}$ (0·375 m). The anchor rope was connected to the model at the bottom ends of board walls. The rope length was so arranged that trials could be made when the rope length was equal to the water depth (moored) and when the rope length was twice as long as the water depth (normally moored).

2.2 *Discussion of experiment results*

2.2.1 *Damping mechanism.* The construction of the floating breakwater in this case was arranged so that the damping mechanism was obtained by the phase difference between the motion of the float and that of incident waves, and the barrier-type float was compared with the pontoon type. It should be stated that since the theoretical analysis of the damping mechanism cannot yet be clarified because of the complexity of the phenomenon, the phenomenon will be explained from the experimental observation.

As a result of the complexity of the damping mechanism of this type of float, it was observed that the float made a rolling motion when immersed up to a certain limit of the draft, but if the draft became smaller than this limit (*ie*, when the float rises higher on the water surface) a heaving motion of the float became predominant.

However, the rolling motion was not the motion around the symmetrical axis of the sectional area of the float. Instead, when the draft was larger and the period of incident waves coincided with that of the float, thereby causing resonance between the float and incident waves, a very peculiar motion was observed in which the land-side wall remained nearly stationary while the sea-side wall made a conspicuous elevating motion (a rolling motion around the asymmetrical axis with respect to the sectional area of the float). When such a motion was generated, the damping effect of the float became very large.

In connexion with the above, it has been alleged that the motion of a float is related in general to the natural period of the float (which is related to the shape of the float, *ie*, to such factors as the draft or material of the float and the interval between the front and rear walls) and to incident waves (especially their period). However, the authors consider that damping mechanisms give damping actions peculiar to respective cases as a result of mutual interference among the most predominant factors under the conditions of particular shapes (intervals of walls in this case) and of the restraining force (of the rope) of various kinds of floats.

2.2.2 *Damping effect.* Before measuring the damping effect, the following preliminary experiment was carried out.

As mentioned previously, the float receives incident waves as a repeated external force applied to it; namely, incident waves give forced vibration to the float. It is, therefore, necessary to consider first how strong the effect of this phase difference is between the period of the float and that of incident waves within a certain range where resonance occurs as a result of coincidence between the two periods (*ie*, within the range where the damping effect is conspicuous). To examine this effect of phase difference, repeated external force which is nearly equal to the natural period of the float has been applied to the float in still water, and the variation in resistance resulting from the float motion has been examined.

In general, when a single force is applied to a float in still water, the float generates vibration and the period of vibration dissipates. In the case of the double-spaced barrier, the dissipation is so quick that measurement of vibration is possible only up to the fourth period at the most. In the preliminary experiment, therefore, measurements of period were made from the second period (where the period is

assumed to be constant) onward and the values of several runs were averaged to determine the natural period of the float. Next, continuous external force was exerted on the float at the above-mentioned period in still water, thereby causing forced vibration of the float; and the variation in resistance due to phase difference was measured. As a result, it was found that the variation in resistance due to phase difference was small and insignificant for practical purposes. From this fact it is possible to surmise that the phase difference accompanying a resonance phenomenon is what makes the damping effect of a float larger.

In such a case, it can be perceived that the interference between incident waves and reflected waves within the float that occurs between the two walls simultaneously with the forced vibration and also the tensile action of the anchor rope exercise their influence upon the float motion; namely, they cause a peculiar float motion stabilizing the rear wall in a stationary state and giving wide elevating vibration to the front wall. This peculiar float motion also explains why the range where a large damping effect can be obtained is so narrow. This peculiar float motion is discussed below, using the same indication symbols as were used in the case of the pontoon.

2.2.2.1 Relationship of damping effect (H_T/H_0) to period of rolling motion of float versus wave period (T/T_w). The damping effect of the barrier-type float is shown in Fig. 1 (1–9). From these graphs, it can be seen that the shapes of the plotted curves can be broadly divided into two kinds according to the difference in appearance of the float motions. Since only three kinds of experiments with $h_w/h_d = \frac{1}{4}$, $\frac{1}{2}$ and $\frac{1}{4}$ were conducted in this case, the transition relative depth (h_w/h_d) of the float motion was not clearly indicated, but the relative depth of the float motion was considered to lie between $\frac{1}{4}$ and $\frac{1}{2}$.

(*i*) *When draft is deep* ($h_w/h_d \geqslant \frac{1}{2}$): In Fig. 1 (1, 2, 4, 5, 7 and 8), the rolling motion is predominant. It can be observed in these graphs that the damping effect in these cases seems to show period variation, though it is not very clear. This may be attributed to the fact that when the period of the waves coincides with the natural period of the rolling motion of the float (*ie*, when $T/T_w = 1{\cdot}0$), the float generates a resonance phenomenon, and simultaneously the water between the front and rear walls acts on the float motion; also, the restraining force due to the anchor rope, *etc*, acts on the float motion simultaneously. Thus, reflection of waves upon the rear wall, waves generated by the motions of front and rear wall, restraining force of the anchor rope and many other factors acting upon the float, cause the phase difference between the period of waves and the motion of the float. Therefore, the damping effect has nothing to do with the wave steepness.

Secondly, the damping effect of a float slightly varies with the magnitude of the interval (a) between the front and rear walls, even if the depth h_w/h_d remains the same. In the case when $T/T_w = 1{\cdot}0$, the larger the interval (a) the better is the damping effect. This is attributable to the fact that when the float motion has the same angle of heel, the larger interval (a) brings about increased stability of the float: namely, the larger the stability, the easier it is to bring about the phase difference.

(*ii*) *When draft is comparatively small* ($h_w/h_d \geqslant \frac{1}{4}$): In Fig. 1 (3, 6 and 9), the damping effect becomes larger as T/T_w increases, contrary to (*i*), but the damping effect has no

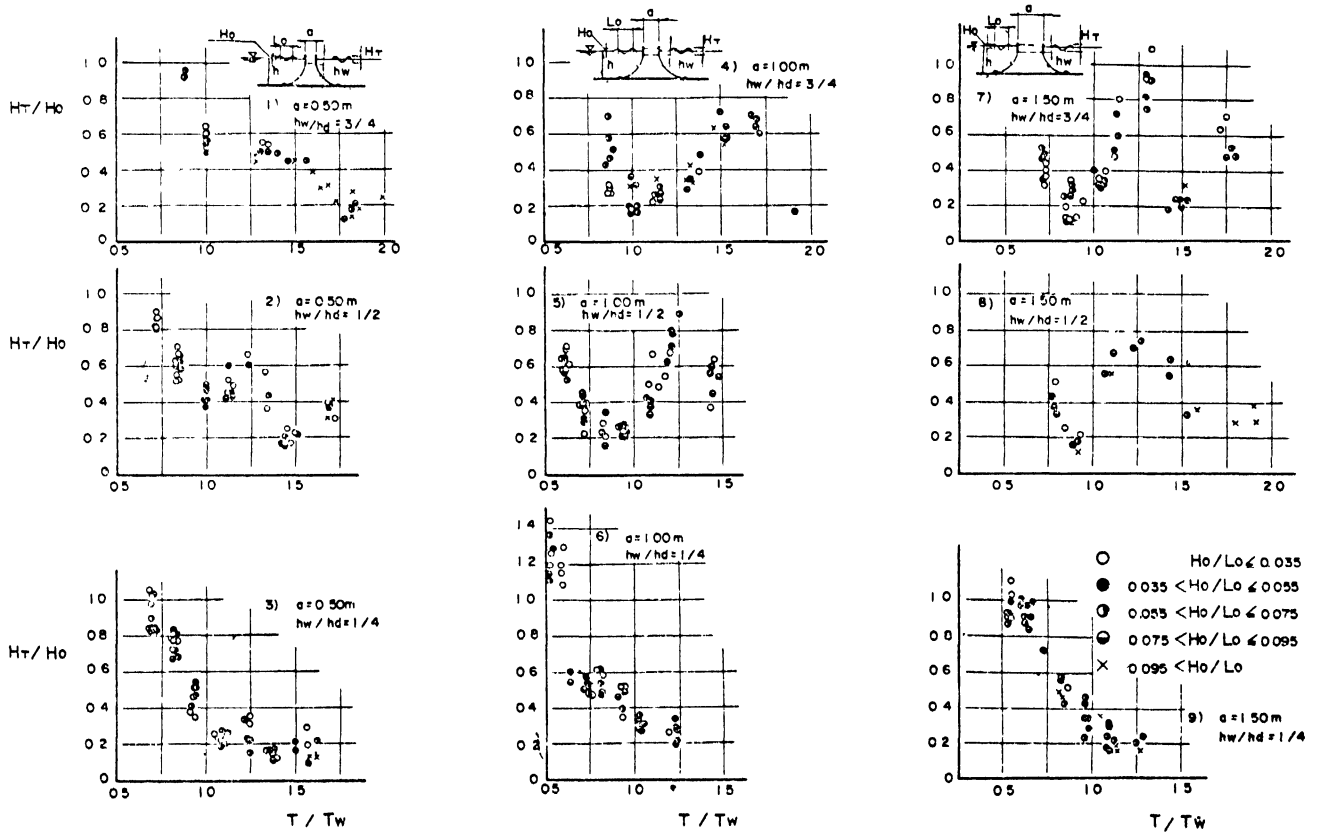


Fig 1. Effect of normally moored floating double-spaced barrier on wave transmission ($H_T/H_0 \sim T/T_w$) for varying board intervals (a) and relative depths (h_w/h_d)

bearing upon the wave steepness as was the case in (*i*). It can be observed that since the draft of the float is smaller, a heaving motion rather than the rolling motion is predominant in this case. As a result, it is indicated that the damping effect is brought about by a damping mechanism based on energy transmission, as opposed to (*i*) where the damping effect was brought about by a damping mechanism based on the rolling motion.

2.2.2.2 Relationship of damping effect (H_T/H_0) to fitting space interval of float versus wave length (a/L_0). In general, the natural period (T) of a float varies with its draft and its waterline area, but in the case of the double-spaced barrier, which may be considered as two independent floats connected at a certain space interval, the time difference in the effect of the secondary waves (arising from vibration) exercised upon the float greatly varies with the fitting interval (a) of the floats as shown above. For this reason, and partly because of design requirements, the relationship between the ratio (a/L_0) of the fitting space interval (a) to the wave length (L_0) and the damping effect (H_T/H_0) is considered in Fig. 2 (1–9).

(*i*) *When draft depth is comparatively large* ($h_d/h_w \geqq = \frac{1}{2}$). The points of the maximum damping effect appear between a/L_0 values of 0·5–1·25 (Fig. 2 (1, 2, 4, 5, 7 and 8)), a trend similar to that in Section 2.2.2.1, and the damping effect deteriorates before and after these two points and also near the middle of the two points. However, the dispersion of the plotted points on the graphs is more conspicuous than in Section 2.2.2.1. These results fit well with those of experiments by Stelzlide and Carr, and the line connecting the upper limits of the dispersion also fit closely with those of Stelzlide and Carr. The reason for this dispersion may be attributed to the degree of strength or weakness of, and the presence or absence of, the restraint by the anchor rope.

(*ii*) *When draft depth is comparatively small* ($h_w/h_d = \frac{1}{4}$). In Fig. 2 (3, 6 and 9), a certain trend is noticeable according to the variation in the float-fitting interval (a). For instance, given $a/L_0 = 0·5$, the comparison of the transmission factors (H_T/H_0) shows that when a = 0·5, 1·0 and 1·50, the values of H_T/H_0 are 9·2, 0·55, 0·80 respectively, thereby indicating that as the fitting interval (a) increases, H_T/H_0 also increases. This means that when the fitting interval (a) is 0·5, 1·0 and 1·5, the wave length L_0 will be 1·9 m, 2·0 m and 3·0 m respectively. If it is assumed that the wave height is constant, the transported quantity of energy per wave length E will be expressed as a ratio of the square root of the wave length L_0; and since $a/L_0 = 0·5$ (constant), the larger the fitting interval (a), the larger will be the wave energy. The present experiments show that since the kinetic energy of the float does not vary very much, the energy of incident waves becomes larger and the damping effect becomes smaller as the fitting interval (a) increases.

From the experimental results described above, the following conclusions can be drawn about the damping effect of the double-spaced barrier:

(*i*) When the period of incident waves more or less coincides with that of the float, the float develops resonance, and if the float is so designed that phase difference will occur due to the draft (and other shape features) of the float, a damping effect can be expected of this double-spaced barrier for practical purposes.

(*ii*) However, compared with the pontoon-type float

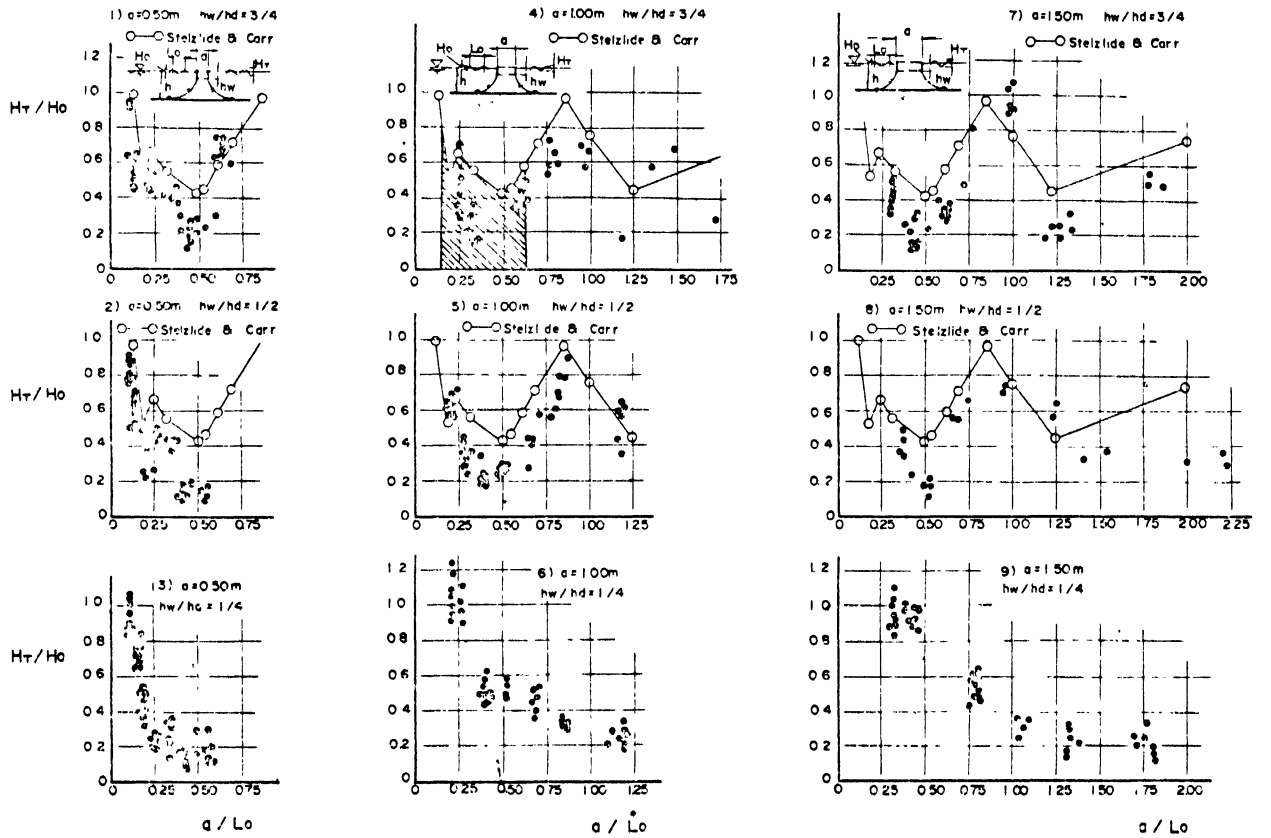


Fig 2. Effect of normally moored floating double-spaced barrier on wave transmission ($H_T/H_0 \sim/L_0$) for varying board intervals (a) and relative depths (h_w/h_d). Results of similar experiments by Stelzlide and Carr in Wiegel (1962) are indicated by O—O

upon which experiments have been conducted by the authors, the double-spaced barrier has a design problem in that the range within which $T/T_w = 1{\cdot}0$ can have a large damping effect is narrower at the time of resonance.

(*iii*) Although graphs in Figs. 1 and 2 can be used as a guide, it was not established how T should be calculated theoretically for designing. After the cross-sections have been determined with the aid of Fig. 2, it is necessary to make the float coincide with the period of the designed waves at the site.

(*iv*) Although the double-spaced barrier as it is cannot be adopted as a practical type of floating breakwater; the main points mentioned above concerning the damping effect will play an important role in designing a practical type of floating breakwater.

3 Wave damping effect of absorber type floating breakwater

3.1 *Experimental procedure*

3.1.1 *Models.* In these experiments, floats in the form of a mattress were used.

Frames in the form of cages were built with hexagonal webs of polyethylene with 30 and 26 mm meshes, filament diameters of 4 and 3 mm and a specific gravity of 0·95. A shock-absorbing material for packaging was used as a filler in these frames. These cages in the form of a mattress were prepared in two sizes, *viz*, 1·0 m × 42 cm × 20 cm high; and 1·0 m × 175 cm × 40 cm high. The buffering or shock-absorbing material used as a filler was cellulose acetate wool.

3.1.2 *Procedure.* The mattress dimensions were changed for height (t) within the range of 0·20–0·60 m and for length of 1·0–3·0 m, while filling the frames.

Adjustment of the depth of the mattress in water was made by attaching small pieces of cellular styrol to the net frame, thus changing the proportion of the above-water height (t_1) to the total height (t) within the range of t_1/t from 0–0·40.

The mattress was moored at the end facing the waves by synthetic fibre ropes (9 mm in diameter and 2·5 m long) tied to the bottom of the water tank.

The water depth (h) of the tank was kept at 1·5 m at all times throughout the experiment.

3.2 *Results and discussions*

3.2.1 *Wave damping mechanism of floating mattress.* Absorption of the energy of incident waves by friction of the molecules of water filling the spaces of the floating mattress is expected as a wave damping mechanism. Therefore, it is important that no phase difference is produced by the movement of the float due to the incident wave, nor should there be a change in the coefficient of reflection resulting from phase difference. In other words, it is essential that the state of movement is scarcely affected by the condition of the incident wave. The mattress should present no natural period of movement that would be seen in the pontoon or barrier system and should have the same damping mechanism whether it has a floating or fixed mooring. Strictly speaking, however, a slight phase difference is produced, as shown in Fig. 3, which compares the damping effects of a mattress float with the above-water height $t_1 = 0$ or $t_1/t = 0$ (shown in black circles) against those with $t_1/t = 0{\cdot}38$ (shown in white circles) the value of H_T/H_0 increases in the former (black circles) with increasing wave steepness, while in the latter (white circles), it is scarcely affected by the wave steepness. This may be explained by the greater wave overtopping when $t_1/t = 0$. This trend remains the same with greater lengths of mattress, only the gradient of the curve varying.

It should be noted that in such an instance the value of t_1 tends to decline at every incidence of wave; that is, the mattress tends to sink.

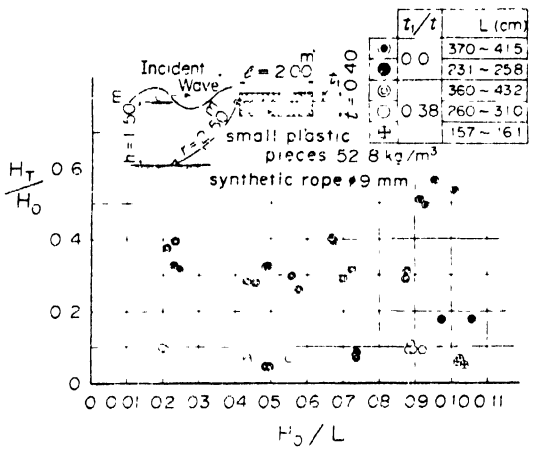


Fig 3. Relation between the transmission coefficient and wave steepness for a mattress float

3.2.2 *Factors affecting the damping effect.* Factors which affect the damping effect include the length and thickness (height in water) of mattress, filling density and physical properties of filling material.

In order to see the influence of the length of breakwater on the damping effect, experiments were conducted as shown in Fig. 4. The figure indicates an instance of the filling density of small plastic pieces packed at 52·8 kg/m³. It can be seen from Fig. 5 that the damping effect is greatly influenced by the parameter d/L. When this parameter is kept constant, higher values of l/L provide increased damping effect. The influence may not be defined clearly from the figure, but it seems that the influence is not linear but exponential (Fig. 5, marked by ⊕ and ○).

The influence of the depth in water (d) of the floating mattress on the damping effect is shown in Fig. 5. The

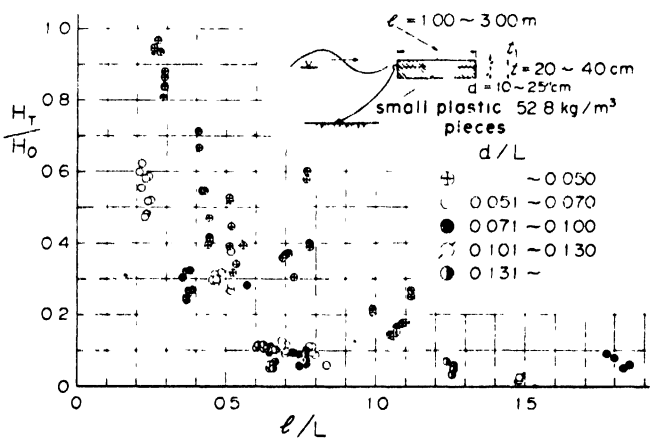


Fig 4. Relation between the transmission coefficient and l/L for a mattress float

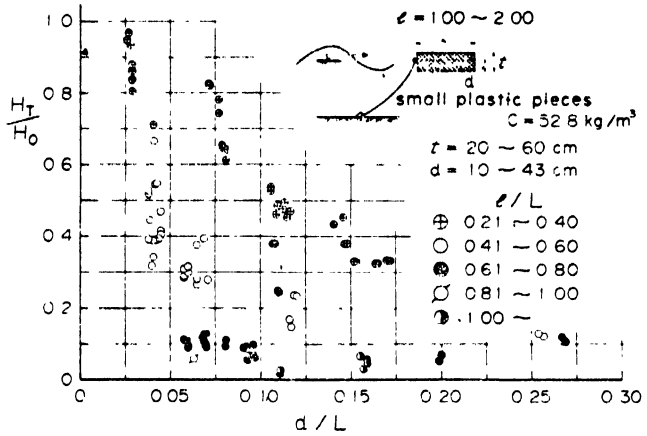


Fig 5. Relation between the transmission coefficient and d/L for a mattress float

figure also indicates an instance of the filling density of small plastic pieces packed at 52·8 kg/m³. In this case too, the damping effect is greatly influenced by the parameter l/L and, when the parameter is kept constant, increases with increasing d/L. It may be seen that this trend is also exponential.

In Figs. 4 and 5, the wave length L was considered as an important factor relative to the transmission of wave energy. The most important problem here is the quantum 'd' represented as the length and that, strictly speaking, it is related to the transmission of wave through the float. It should, therefore, be regarded as a two-dimensional quantum.

3.2.3 *Wave damping effect.* As described in the foregoing sections, the damping effect of a breakwater of the wave energy absorptive type, of which the damping effect is by frictional action alone, is generally expressed as an exponential function. Assuming that the wave damping mechanism permits application of the process of power transmission if the reflection by the float is neglected, a comparison of the transmisssion coefficient curves for different components can be made as shown in Fig. 6. Although some dispersions are noted, the power transmission of the energy of incident waves by friction in the damping (mattress) breakwater can be readily explained. The dispersions are considered to be due to overtopping. The overtopping phenomenon was greater with greater incident wave and had an influence where the value of

$$\left\{1 - \frac{\sinh 2k(h-d)}{\sinh 2kh}\right\} \cdot \frac{l}{L} \text{ was small.}$$

Where the filler consists of buffering material, the damping effect varies with the filling density and increases proportionately with the filling density. In Fig. 6, the ' ○ ' symbols represent a filling density of 26·4 kg/m³, while the black symbols represent a density of 52·8 kg/m³. When the respective values of resistance coefficient α are read from the graph, they are 4·5 in the case of the former and 9·0 in the case of the latter, and are in exact proportion to the filling densities.

In the case of the plastic balls (symbol Δ), application of the power transmission theory is rather difficult. The reason for this is that where the ball diameter is great as compared

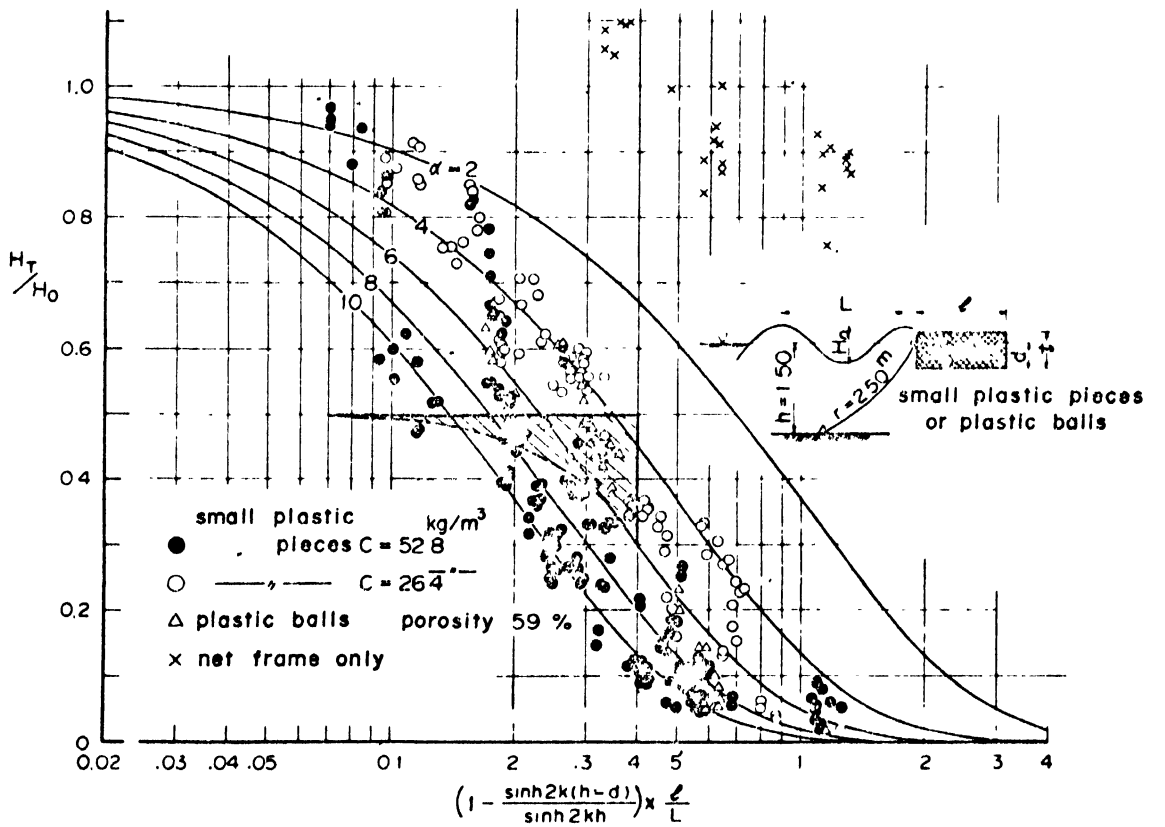


Fig 6. Comparison of the transmission coefficient curves for different mattress breakwater components (a resistance coefficient varying with the filling material and filling density)

with the incident wave length, the reflection due to the balls is great; for the waves of large wave length, the balls make a movement complying with the orbit of water molecules, so that in either instance the mattress produces no frictional action against the incident waves.

As described in the foregoing, where the damping mechanism of the mattress is dependent solely on the absorption of the energy of incident waves by friction, it may be possible to generalize the expression of the damping effect by appropriate determination of the value of α. Thus, it is relatively easy, in the present case, to find a similarity for field application, and resolve the outstanding problem in the case of the sheet type or flexible breakwater utilizing phase difference.

Expression of the damping effect of a wave energy absorber by frictional action must take into consideration the resistance coefficient α, which represents the filling density and physical properties of the filler.

4 Shape of a practical floating breakwater

4.1 *Design conditions for practical construction of non-flexible floats*

For practical purposes how large should a float be in order for it to dissipate winds and waves?

If the objective is to make the floating breakwater feasible in the present stage of technology, the following design conditions may be adopted. If the expected damping effect is taken as 50% or more, height of designed wave is 3 m or less, and wave steepness is 0·06 or less, then floats having the following ranges of features will meet the above-mentioned conditions: length of float (a)$=\frac{1}{4}$ to $\frac{1}{2}$ of wave length; draft of float $(h_w)-H_0/2$.

If the above ranges are acceptable, the wave length and the wave period can be calculated as follows: With wave steepness of 0·02–0·06 and wave height of 2·0–3·0 m, the wave length will be 33–150 m, and the wave period 5–10 seconds in accordance with the theory of small amplitude waves.

4.2 *Basic float shape*

The float interval (a), which represents the approximate scale of the float shape, is calculated using Fig. 2 as a guide, and taking into account the wave conditions given in Section 4.1, as shown below. (Fig. 2 (4) is shaded to indicate the ranges where $2l = 25$ m is taken as the practical upper limit.)

If the maximum length of $2l$ is taken as 25 m, the area distribution of values of a less than 25m in the table below will determine the appropriate scale. Since the demarcated values have a wide margin of allowance, there is considerable flexibility in design limits to suit actual situations.

If the float designed according to the table below is found theoretically correct and analogous to the results obtained by indoor experiments, then it will be necessary to examine with the aid of Fig. 2 how large the scale of waves will be that a float of this size can cope with.

As has been described in section 3, it is impossible to calculate accurately the rolling period of the double-spaced barrier because the motion of water between the two walls of the float interferes with the walls at the time they roll. Therefore, the rolling period of the double-spaced barrier is calculated only as a rough guide, using the same formula as was used in the case of the pontoon.

The lateral vibration period of a float can be calculated with the following formula:

$$T = \sqrt{\frac{r^2}{g\overline{GM}}} = 2\pi\sqrt{\frac{I}{g.W.\overline{GM}}}$$

where r = rolling radius
I = rotary inertia moment
W = displaced weight
GM = height of metacentre

The lateral oscillation period of the float designed according to the above formula will be about 2·0 seconds regardless of the variation in the float interval (a) or in the centre of gravity. The reason for this may be attributed to the fact that the stability of the float is large (namely, the travelling moment of the displacement becomes larger), and the water level surface moment with respect to the displacement is large.

It can be readily observed that there is a wide disparity between the period of 2·0 seconds for the lateral oscillation compared to the period of the designed waves, *ie*, $\geqslant 10$ seconds. In other words, a float of the given scale can only cope with waves where $T_w = 2{\cdot}0$ seconds. Consequently, a float modelled on the double-spaced barrier is practically useless as far as the damping effect is concerned, and this fact has been clearly demonstrated by a field test.

It is therefore necessary to consider measures which will make the lateral oscillation period larger for an effective design.

4.3 *Design conditions for practical construction of a flexible float*

The expected damping effect in this case also is taken as 50% or more. Under this assumption, the designed waves will have steepness (H/L) of 0·04 or less, and wave length (L) of 100 m or less. With respect to these designed waves, the size of the mattress float may be given the following values which are practical from the viewpoint of available material and economy.

Height of designed wave (m)	*Damping effect* H_T/H_0	*Steepness* $2l/L_0$	0·02 a = 2*l* (m)	0·03 a = 2*l* (m)	0·04 a = 2*l* (m)	0·05 a = 2*l* (m)	0·06 a = 2*l* (m)
2·0	0·4 to 0·6	0·25	25·0	17·0	12·5	10·0	8·4
	0·1 to 0·3	0·50	50·0	33·4	25·0	20·0	16·7
3·0	0·4 to 0·6	0·25	37·5	25·0	18·8	15·0	12·5
	0·1 to 0·3	0·50	75·0	50·0	37·5	30·0	25·0

Mattress length (l)= less than $\frac{1}{2}$ wave length

Distance from still water surface to bottom line of float (d)= 1·5 m

In each case, the water depth (h) at the site is 20–30 m. The sizes of the mattress float (l) and the appropriate values of L (assuming sea-water density to be constant) are obtained as shown below. The area shaded in Fig. 6 shows practical design limits used in obtaining the following data.

$$\text{Values of} \left\{ 1 - \frac{\sinh 2k(h-d)}{\sinh 2kh} \right\} \cdot \frac{l}{L}$$

L	l	*Water depth* (m)					*Resistance coefficient of filling material* (α)
		30	20	15	10	5	
100	50		0·0878	0·0911	0·1033	0 1623	9:18 (50% damping)
75	30		0·0727	0·0898	0·0959	0·1348	10:19
50	25	0·1296	0·1477	0 1583	0·1607	0·1921	7:9
25	15			0·3020	0·3109	0·3232	5:6
20	15				0·4451	0·4631	5:6
20	10				0·2967	0·3087	3:4

4.4 *Shape of a floating breakwater for practical development*

From the above, it is considered that a combination of the double-spaced barrier and the absorber mattress will provide the most practical and feasible design for a floating breakwater in marine waters.

5 Conclusions

(*i*) With the object of developing floating breakwaters, the nature of float resistance (*ie*, damping effect) of the basic shapes of all kinds of floats with respect to incident waves has been clarified. Floats can be classified according to their damping functions into immutable floats (due to phase difference reflection) and flexible floats (due to friction).

(*ii*) It is suggested that a practicable floating breakwater should be a combination of the immutable and flexible floats.

(*iii*) After further studies into float anchoring, materials to be used and execution of construction in respect of the shape of the float as suggested in the present paper, and by conducting field experiments, it will be possible to design a floating breakwater for practical use.

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Progress in Farming Turbot, *Scophthalmus maximus*, in Floating Sea Cages

S. T. Hull and R. D. Edwards

Abstract

The British White Fish Authority has been involved in the research and development of farming methods for marine flatfish since 1965. From 1971 trials with turbot, *Scophthalmus maximus*, have been conducted in experimental cages, of 3 m^3 volume, floating in a sheltered area of a sea loch on the west coast of Scotland.

Six stocks of fish of wild origin, having mean weights between 33 and 79 g were transferred from an onshore nursery in May or June, 1972, 1973, 1974 and 1975. Hatchery-reared fish, from a successful season in 1974, provided two stocks, having mean weights of 38 and 80 g, for transfer to the cages in 1975. Weight increases of 143% and 114% in hatchery stocks over the first six months compared favourably with weight increases of 107% and 104% from similar stocks of wild origin. Mean weights of 240 g were achieved after 12 months, 590 g after 24 months and 1 230 g after 29 months of sea-cage growth with the 1972 year-group turbot.

Numerical densities of 30, 81, 110 and 240 fish per m^3 have been investigated with maximum stocking levels ranging from 34·7 kg/m^3 with turbot at 28 fish per m^3 to 41 kg/m^3 with turbot held at 240 fish per m^3; growth and survival were independent of density up to the levels so far evaluated.

Fish fed on moist pellet diets, formulated and manufactured by the Authority, have yielded wet-food to wet-fish conversions of 2:1 and conversion efficiencies of up to 50%. Similar conversions and conversion efficiencies have been obtained with a cheaper food, unprocessed sprats, *Sprattus sprattus*.

No disease problems have been encountered, and survivals have been in excess of 90% for all stocks with several exceeding 98%.

Progrès en élevage en mer du turbot, *Scophthalmus maximus*, dans des cages flottantes

Résumé

La British White Fish Authority s'occupe depuis 1965 de recherches et de développement dans le domaine des méthodes d'élevage des pleuronectidés marins. A partir de 1971, des essais ont été réalisés avec des turbots (*Scophthalmus maximus*) dans des cages expérimentales de 3 m^3, flottant dans une zone abritée d'un loch marin sur la côte occidentale de l'Ecosse.

Des stocks de poissons d'origine sauvage, d'un poids moyen de 33 à 79 g, ont été transférés à six reprises à partir d'une alevinière côtière, en mai ou en juin (1972, 1973, 1974 et 1975). Les poissons élevés en écloserie au cours d'une saison favorable (1974), ont fourni deux stocks, d'un poids moyen de 38 et 80 g, destinés à être transférés dans les cages en 1975. L'augmentation de poids, 143 et 114% des stocks d'écloserie au cours des six premirs mois est tout à fait favorable, comparé aux augmentations de 107 et 104%, constatées sur des stocks similaires d'origine sauvage. On a obtenu des poids moyens de 240 g après 12 mois, de 590 g après 24 mois et de 1 230 g après avoir élevé en mer, pendant 29 mois en cages, des turbots du groupe de l'année 1972.

On a étudié le stockage à raison de 30, 81, 110 et 240 poissons par m^3, au taux moyen d'empoissonnement variant entre 34,7 kg/m^3 pour les turbots maintenus à raison de 28 spécimens par m^3 et de 41 kg/m^3 pour les turbots maintenus à 240 unités/m^3; les taux de croissance et de survie sont indépendants de la densité, aux niveaux évalués jusqu'ici.

Les poissons nourris de granulés humides, formulés et fabriqués par l'Authority, ont obtenu un taux de conversion alimentaire aliments humides: poisson humide égal à 2:1 et une efficacité de la conversion atteignant 50%. On a obtenu des taux et efficacités de conversion analogues avec un aliment moins onéreux, des sprats non transformés (*Sprattus sprattus*).

Aucune maladie ne s'est produite et les taux de survie ont dépassé 90% pour tous les stocks, et même 98% dans certains cas.

Avances en el cultivo de rodaballo, *Scophthalmus maximus*, en jaulas flotantes

Extracto

La White Fish Authority de Gran Bretaña se ocupa desde 1965 de estudiar y fomentar métodos de cultivo de peces planos marinos. Desde 1971 vienen realizándose ensayos de cria de rodaballo (*Scophthalmus maximus*) en jaulas flotantes experimentales, de 3 m^3, en una zona protegida de una ensenada de la costa occidental de Escocia.

Durante los meses de mayo o junio de 1972, 1973, 1974 y 1975 se

trasladaron desde un criadero situado en tierra seis grupos de peces de origen silvestre, con pesos medios de entre 33 y 79 g. Peces de criadero, de una incubación realizada con éxito in 1974, dieron dos grupos que se colocaron en las jaulas en 1975, con pesos medios de 38 y 80 g. Los grupos incubados en vivero registraron durante los seis primeros meses aumentos de peso del 143 y el 114%, respectivamente, mientras el aumento de peso de grupos análogos de origen silvestre fue del 107 y el 104%. Con los grupos de rodaballos de 1972, cultivados en jaulas, se logró un peso medio de 240 g al cabo de 12 meses, 590 g a los 24 meses y 1 230 g a los 29 meses.

Se ha estudiado el crecimiento a densidades numéricas de 30, 81, 110 y 240 peces por m^3, con niveles máximos de siembra que oscilaron entre 34,7 kg/m^3, con una densidad de 28 rodaballos por m^3, y 41 kg/m^3, con una densidad de 240 rodaballos por m^3. Con los niveles de siembra evaluados hasta la fecha, el crecimiento y la supervivencia han resultado ser independientes de la densidad.

Alimentando a los peces con raciones a base de gránulos húmedos, preparadas y fabricadas por la White Fish Authority, se han obtenido índices de conversión de alimentos húmedos a pescado fresco de 2:1, con una eficiencia de conversión de hasta el 50% y eficiencias de conversión similares se han conseguido con piensos más baratos a base de espadín (*Sprattus sprattus*) sin elaborar.

No ha habido ningun problema de enfermedades, y en todos los grupos la supervivencia ha sido más de 90%, y en varios incluso más del 98%.

1 Introduction

The first attempts by the British White Fish Authority to hold flatfish in floating cages in the sea were undertaken in 1969 after four years of cultivating marine fish in various types of holding facilities in an intertidal sea pond (Howard and Kingwell, 1975). During the early development, 1965–71, plaice, *Pleuronectes platessa*, was successfully used as the experimental animal to determine husbandry and management criteria for rearing marine flatfish to suitable market size (Howard, 1974). Since 1970 the emphasis has been changed to other species of marine flatfish native to coastal waters around the British Isles which, by commanding a higher price, offered a more attractive proposition to potential commercial fish farmers (Jones, 1972; Kerr, 1974).

With salmonid species excluded from the Authority's brief, because they are in terms of its act of constitution not considered to be 'white fish', there were three possible contenders. Dover sole, *Solea solea*, require warmer water than the UK ambient for rapid growth, therefore the Authority's work with this species has been conducted only in onshore tanks in water warmed by cooling the condensers of the electrical generating station at Hunterston in Scotland (Kingwell, 1974). The other two species, turbot, *Scophthalmus maximus*, and halibut, *Hippoglossus hippoglossus*, were considered suitable for investigation in sea cages at the Authority's Farming Unit, Ardtoe, Scotland, where a system for growing flatfish in a sheltered sea loch, after an initial period of growth in onshore tanks, was being developed. Turbot have been fattened in sea cages since 1971 and spawning stock have been maintained at Hunterston since 1968. Trials with halibut have just started and are therefore not discussed here.

The slow development of a reliable hatchery technique for turbot has hindered experimental work into its early growth stages. However, the capture of newly metamorphosed fish of wild origin from beaches, each year since 1971, has enabled limited husbandry trials to be undertaken in parallel with hatchery development. Since 1970, when the Ministry of Agriculture, Fisheries and Food first hatched turbot successfully, the number of hatchery produced juveniles has increased annually, with significant numbers being achieved in 1974. Hatchery fish produced by the Authority in 1974 were used for the first time in sea cage trials during 1975.

Initially, the objectives were to determine both growth potential and survival of stocks held in ambient sea water in floating cages, and in the process to identify husbandry techniques and any problems of health. As more fish became available for experimentation, the programme was extended to investigate the type and frequency of feeding, and the effect of increasing the stocking density in the cages. All experimentation was conducted with commercial application in mind, the eventual objective being the demonstration of the Authority's developments on a pilot commercial production scale.

2 Methods

2.1 *Supply of stock*

All turbot juveniles, whether of hatchery or wild origin, underwent a nursery period of up to one year, being held in onshore tanks (Smith, 1979) before transfer to sea cages. Wide size variations in the stock at transfer were largely attributed to differences in the results of the development trials under the holding regimes tested during the onshore period. The youngest turbot accepted for sea-cage trials were between 11 and 13 months old, with weight variations between 10 and 105 g. Of the eight stocks of fish held, six were of wild origin from 1971, 1972, 1973 and 1974 year-groups, and two were of hatchery origin of the 1974 year-group (White Fish Authority, 1975).

2.2 *Sea-cage site*

A nearby sea location in Loch Moidart, Inverness-shire, was chosen (Fig. 1) as it was sheltered from the prevailing southwest wind and gave satisfactory protection to floating structures. Hydrographic records over five years show that ambient surface sea temperatures varied from minimum winter conditions of 6·0°C to maximum summer temperatures of 16·4°C (Fig. 2). Surface salinities in the area were within the range 29·0–33·8 ppt with a 1% incidence per year of salinities below 29‰. Dissolved oxygen content, measured at irregular intervals, was within the range 96–112% saturation.

The cages were moored in a small bay close to the shore

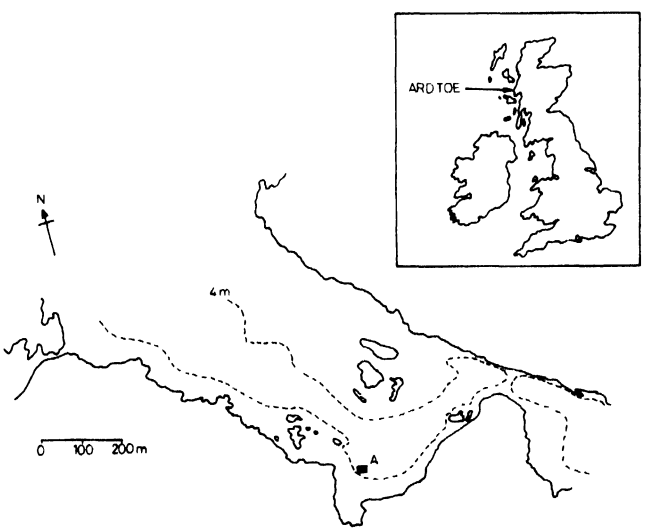


Fig 1. Location of the White Fish Authority's sea-cage site near Ardtoe, Argyllshire, Scotland

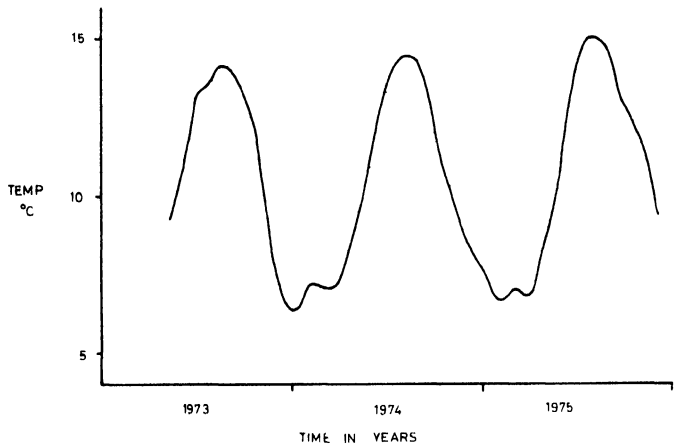


Fig 2. Ambient surface sea temperature (°C)

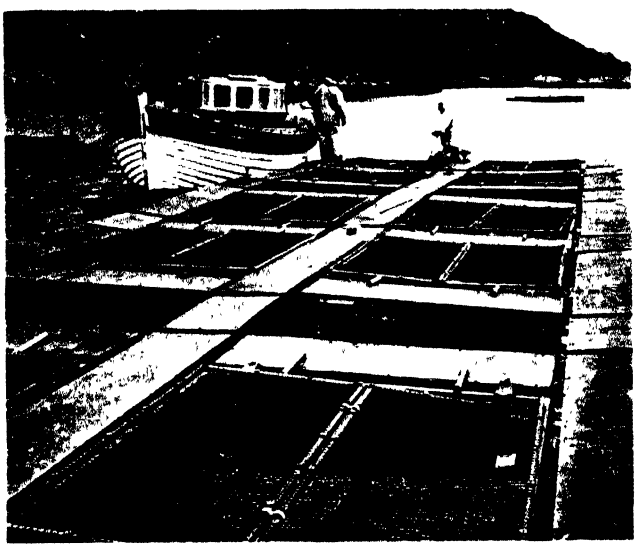


Fig 3. Experimental floating cage system used for turbot cultivation trials

in an area of good tidal flow with a range of 5 m at spring tides. Current speeds in the general area of the cages reached a maximum of 28·9 cm/second with speeds exceeding 10 cm/second for 85% of all tidal cycles. Interchange rates in excess of 600 m^3/hour were recorded within floating cages of 3 m^3 enclosed volume, at a current speed of 17·6 cm/second.

2.3 *Experimental holding facility*

The necessity for replicate trials influenced the size and design of the floating cages used. The system developed involved groups of four relatively small cages, with a common buoyancy, anchorage and access system, linked to other groups at right angles (Fig. 3) (Howard and Kingwell, 1975).

Each cage was 1·8 × 1·8 × 1·2 m deep, constructed of 38 mm angle iron clad with 12·7 mm square aperture plastic coated welded mesh (Weldmesh, United Wire) with a working volume of 2·9 m^3. The cage floor had a solid surround of fibreglass with a central section of rigid plastic-coated Weldmesh, the areas being in the ratio of 60:40 respectively. Buoyancy was provided by 82 litre plastic barrels (Chas. Tennant), filled with expanded polystyrene, enclosed in an angle-iron frame having a marine ply surface. The buoyancy units were arranged so as to give access to each cage from all four sides. Each cage was supplied with a hinged lid made of Weldmesh attached to a PVC framework to protect the stock from predators, especially gulls and herons.

2.4 *Husbandry and sampling routine*

The stock were fed five days a week, to satiation except in trials to investigate the feeding of percentage weights of total biomass.

Because of the small size of the experimental cages, it was easy to observe the fish, without disturbance, for any external signs of disease or damage, whilst cage cleaning and maintenance could be performed by two men. The numbers of stock were restricted by the small cage size, enabling 100% samples to be carried out at interim stages of trial experiments, when individual weight (in g) and length (tip of the lower mandible to the tip of the caudal fin to the nearest mm below) measurements were recorded.

2.5 *Feed types and composition*

Following extensive experimentation by the Authority (Thain and Urch, 1972, 1973) several dietary formulations acceptable to marine flatfish were developed. At present two semi-moist pellet formulations, WFA6 and WFA7 (Tables I and II) are in use together with a diet consisting of whole sprats, *Sprattus sprattus*.

TABLE I
PERCENTAGE COMPOSITION OF MANUFACTURED PELLET DIETS

Food type	*WFA6 pellet*	*WFA7 pellet*
Fish meal	40	40
Reclaimed filleting offal	20	—
Sprat	—	20
Queen scallop	-	20
Tap water	20	-
Soybean derivative	5	—
Cooked wheat	—	15
Vitamin/binder mixture	15	5
Total	100	100

TABLE II
ANALYSIS OF FOOD TYPES

Percentage composition	*Pellet*		*Sprat*
	WFA6	*WFA7*	
Moisture	40·7	40·7	75·0
Ash	12·4	9·5	2·3
Protein	38·8	36·4	14·8
Oil	5·0	4·2	7·9
Carbohydrate (by difference)	3·1	9·2	0
Total	100·0	100·0	100·0

A moist paste formulation, encased in an artificial skin in sausage form, was used in early trials but was superseded by the pellet diets. One proprietary brand of salmon pellet (Tess, Skretting) was used for a short comparative trial.

3 Results and discussion

3.1 *Growth and growth rate*

The mean increases in weight for the stocks are given in Fig. 4. Comparison of this with the temperature graph (Fig. 2) shows clearly the relationship between temperature and growth, with good growth being achieved during the period

TABLE III
PERCENTAGE INCREASE IN WEIGHT IN STOCKS OF TURBOT DURING PERIODS OF SUMMER AND WINTER GROWTH

Year-group	Stock	Number of fish	Mean weight (g) at 13 months	Percentage increase in mean weight					
				Fish age 13-18 months (June-November)		Fish age 19-23 months (December-April)		Fish age 24-29 months (May-October)	
				Total period	Monthly average	Total period	Monthly average	Total period	Monthly average
1972	W1	98	65·0	89·1	15	40·8	8·2	252·4	42
1973	W2	345	40·3	46·1	7·7	34·1	6·8	211·4	35
	W3	360	33·0	110·8	18	33·8	6·8	205·8	34
1974	W4	720	78·9	104·1	17				
	W5	720	35·2	106·8	17	Not available at time of writing			
	H1	345	80·2	113·9	19				
	H2	345	38·0	143·2	24				

of May-November, peaking in August, and slow growth during the remainder of the year. The percentage increases in weight for the different growth periods are given in Table III.

Due to the individuality of the different year-groups, held under varying husbandry and management regimes, no direct comparisons of growth during different years can be made. However, from inspection of Fig. 2 and Table III it can be seen that growth rates of fish during the first summer in cages (months 13–18) were slightly better in 1975 than in 1974 or 1973 and that temperatures during 1975 were slightly warmer than in preceding years. This apparent growth enhancement did not occur with stock held in their third summer of growth (months 24–29).

The mean weight and timing of transfer of the juveniles from onshore to sea cages have been shown to be important if the stock were to achieve a desired final, or harvesting, weight at the end of a summer growth period. At present, marketing trials (Kerr and Howard 1975; White Fish Authority, 1975a) have shown the desired weight for harvesting to be just under 500 g, which, as can be seen from Fig. 4, is achievable at the end of the second summer, providing the fish averaged 50 to 60 g or more when transferred from the nursery. Fig. 5 gives the growth for seven stocks during the first six months in cages.

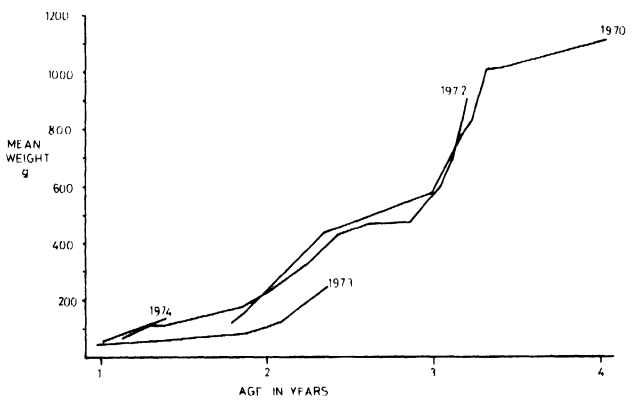


Fig 4. Mean weight increases for 1970, 1972, 1973, 1974 year-groups of turbot held in 3 m^3 floating sea cages

3.2 *Variation in growth*

It has been noticed from the earliest farming trials that there is a large variation in growth amongst fish of the same stock. This variation was apparent in O-group turbot (Smith, 1979) as well as in older year-groups, and was not related to the growth differential between the sexes of the species (Jones, 1972; Purdom, Jones and Lincoln, 1972) which only became apparent at the onset of gametogenesis in their third year of growth (II-group). The manner in which the spread of variation in weight increased with age in two stocks of I-group turbot of wild and hatchery origin is shown in Table V.

3.3 *Comparison of growth between juveniles of hatchery and wild origin*

Growth of the hatchery stock (H1 and H2) when compared with stocks of wild origin of the same year-group (W4 and W5) showed some superiority (Table IV and Fig. 5) and a greater uniformity in size. This superior performance, which was also apparent in the food conversion efficiency, was possibly linked to differences in behaviour noted between the two stocks. Hatchery turbot were less active than their wild counterparts, even during feeding. Furthermore, unlike fish of wild origin, there was no evidence of either fin-biting or aggression. One offsetting factor was that hatchery turbot were more active when handled and therefore more liable to adverse effects from the stress of being measured.

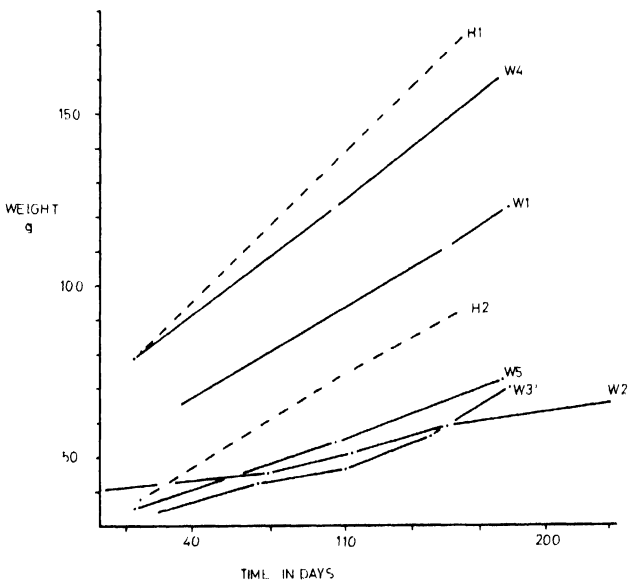


Fig 5. Growth of groups W1-W5, H1-H2 of I-group turbot (see Table III for stock description)

3.4 *Stocking density*

As insufficient numbers of turbot were available in the earlier years, detailed experiments on growth density relationships have yet to be undertaken with identical stocks. The interpretation of results to date must take into account

TABLE IV

GROWTH IN GRADED STOCKS OF I-GROUP TURBOT OF HATCHERY AND WILD ORIGIN DURING THE FIRST SIX MONTHS IN SEA CAGES: WEIGHT GAIN, SURVIVAL, DENSITY, FOOD CONSUMPTION AND CONVERSION DATA

Stock origin	*Initial weight (g)*	*Weight (g) at month 6*	*Weight increase (%)*	*Survival (%)*	*Biomass (kg/m^3)*	*Food consumed (kg)*	*Wet weight food conversion ratio*	*Conversion efficiency (%)*
H1	80·4	172·9	114	100	20·57	56·87	1·78	56·1
H2	38·0	92·4	143	100	10·96	38·58	2·06	48·6
W4	78·9	161·0	104	98·6	39·63	131·28	2·26	44·2
W5	35·2	72·8	107	98·3	17·74	72·50	2·78	35·9

TABLE V

VARIATIONS IN WEIGHT DISTRIBUTION IN WILD AND HATCHERY STOCKS

	Distribution at 12 months as percentage of total stock		*Distribution at 15 months as percentage of total stock*		*Distribution at 17 months as percentage of total stock*	
Weight range (g)	*Wild origin*	*Hatchery origin*	*Wild origin*	*Hatchery origin*	*Wild origin*	*Hatchery origin*
25–49	7·8		0·7		0·4	
50–74	51·4	44·6	13·6	2·3	6·6	1·4
75–99	22·2	38·8	22·7	13·6	16·5	5·5
100–124	10·1	12·5	23·6	27·5	17·0	12·4
125–149	4·6	3·5	14·6	21·2	14·3	20·6
150–174	2·4	0·6	9·2	16·2	11·2	18·2
175–199	0·8		5·2	11·6	10·2	12·6
200–224	0·6		4·0	4·1	4·6	10·4
225–249	0·1		3·5	1·7	5·8	8·1
250–274			1·1	1·2	3·2	4·9
275–299			1·1	0·6	2·4	3·5
300–324			0·3		2·5	0·6
325–349			0·3		1·7	0·9
350–374					1·0	0·6
375–399					1·3	0·3
400–424					0·6	
425–449					0·1	
450–474					0·3	
475–499					0·1	
500–524					0·1	
525–549					0·1	

the inherent differences between stocks and holding conditions. Limiting stocking rates have not yet been encountered, with the maximum to date being 41 kg/m^3 at 240 $fish/m^3$ with I-group and 34·7 kg/m^3 at 28 $fish/m^3$ with III-group turbot (cf. 87 kg/m^3 at 232 $fish/m^3$ with plaice (Howard and Kingwell, 1975)). As with plaice, stocking density significantly affects the feeding response (Kingwell, 1974), with greater feeding activity being maintained with fish stocked at high density (240 $fish/m^3$) than at lower densities (30, 81 and 110 $fish/m^3$). Perhaps surprisingly, there was no significantly detectable change in food conversion with density, but further trials are necessary to prove this positively. It has been established that grading of stocks held at high density is necessary at least once a year to maintain adequate growth in all size groups, by minimizing the size divergence.

3.5 *Feed and conversion efficiency*

In this paper, conversion rates are based on the ratio of wet weight of food fed to wet weight increase in fish. The type of food and its composition have been altered over the years to achieve reductions in cost consistent with a high nutritional value. Initially, whilst trials were at an experimental stage, the food conversion rates were poor, at around 14:1 when using an artificial diet with a protein content of 14%. Since then the conversion rate has been improved to 2:1 (Tables IV and VII) whilst similar rates have been achieved using a lower cost sprat diet (Table VI). Overall achievement of growth was greatest with the sprat diet. One such trial result is shown in Table VI.

Sufficient data were obtained to determine the correlation between temperature and food consumed, shown in Fig. 6 as the relationship between food eaten, expressed as a percentage of body weight and temperature, over a 13 month period for 1973 wild stock turbot at a density of 80 $fish/m^3$, fed a pellet diet (WFA6) to satiation five days a week throughout. The maximum satiation feeding level

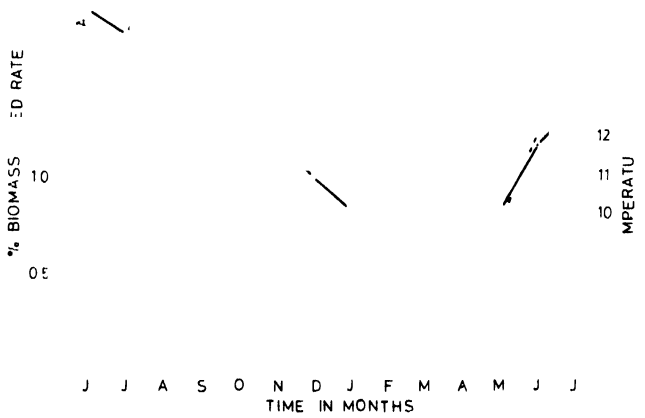


Fig 6. Food consumption variation with temperature (°C) for turbot held at 30 $fish/m^3$ between 12 and 25 months

TABLE VI
TRIAL RESULT FOR STOCKS OF II-GROUP TURBOT AT 39 FISH/M³ FED ON THREE DIETS

Diet		WFA6		WFA7		Sprat	
		Day 1	Day 77	Day 1	Day 77	Day 1	Day 77
Number of fish		113	110	113	106	113	111
Survival	%		97·3		93·8		98·2
Biomass	kg	46·9	66·4	46·8	65·4	47·2	71·8
Biomass increase	kg		19·5		18·6		24·6
Mean weight	g	415	603	415	617	418	647
Mean length	cm	26·7	29·4	26·6	29·4	28·2	29·7
Food eaten	kg		40·1		37·5		54·6
Conversion ratio, wet wt:wet wt			2·05:1		2·0:1		2·2:1
Conversion efficiency			48·6		49·5		44·9

TABLE VII
GROWTH OF III-GROUP TURBOT AT 28 FISH/M³: MONTHS 37–41 FROM HATCHING FED ON SPRATS

Month	No. of fish	Mean length (cm)	Mean weight (g)	Mean weight increase (g)/fish/day	Percent biomass feed rate	Wet-weight conversion	Conversion efficiency
37	82	28·7	593				
38	82	29·9	697	4·00	1·47	2·21	45·3
39	82	32·0	909	5·87	1·56	2·03	49·2
41	82	35·6	1 228	4·15	0·41	2·20	45·4

dropped as the fish aged, falling from 2·5% of body weight per day with I-group fish to 1·5% with II-group fish, during the period of maximum feeding response in mid-summer. The minimum occurred when the sea temperature fell to 6°C and was 0·45% for I-group fish.

3.6 *Survival and health*

Survival in all year-groups was good, ranging from 91 to 100%. It is interesting to note that the turbot of hatchery origin have shown 100% survival over the initial six-month period to the date of writing.

The majority of the mortalities recorded were of the smaller fish in the respective populations, either as a result of starvation (inability of the fish to compete with the remainder of the population for food), or as a result of algal growth within the cage. The growth of filamentous algae, most notably *Enteromorpha* sp., has on occasion caused mortality in some small I-group fish due to accidental ingestion of the algae resulting in gill occlusion and asphyxiation.

No ectoparasites were observed during the trials. The tape-worm, *Bothriocephalus scorpii*, was observed in faecal matter within some cages but this did not appear to affect growth rates or condition of stocks. The bacterium, *Vibrio anguillarum*, the cause of considerable mortality in onshore tanks (Smith, 1979), if present, did not visibly affect any of the stocks held.

Apart from the losses described above, the stocks all exhibited a healthy stress-free behaviour, with vigorous feeding activity being maintained even after handling or stock measurements.

4 Conclusions

It is already apparent that turbot are suited to the farming conditions experienced in floating cages in the sea on the west coast of Scotland. From over 5 000 fish held under trial conditions, significant growth and survival figures have been obtained. Survival in particular has been encouraging with all year-groups being in excess of 90% and several being over 98%.

The initial growth rates of the different stocks suggest that the fish should be at least 50–60 g before transfer to sea cages. This transfer weight was readily achievable within 12 months from hatching (Smith, 1979), the time at which the sea temperature is becoming sufficiently high to allow the transfer to take place, without detriment to growth.

Increasing the stocking density to 240 fish/m³ (giving a maximum stocking biomass to date of 41 kg/m³) has not depressed growth, when compared with that of other stocks held at lower densities, and it has positively aided feeding activity.

With the ambient seawater temperature ranging from 6°C to 16°C, and for approximately 26 weeks each year above 10°C—the temperature at which growth becomes marked—the growth can be split into distinct phases. On transference from the onshore tanks there was a 6 month growing phase, from June to November, when the mean weight of the stock increased rapidly (Table II), then a period of slow growth, between December and April which coincided with the low water temperature, followed by another rapid growth phase as the sea temperature again rose. Peak growth occurred in August each year when feeding activity was most pronounced.

Under the farming conditions being investigated, the period of slow growth in the winter months may well prove to be acceptable, as a market size of 450–500 g has been achieved by the following October/November, *ie*, at an age of 30 months from the egg, including 18 months of ongrowing. Holding the fish for a further year has given a mean weight of 1·2 kg. Although this growth rate is slower than can be achieved in warmed water (Purdom, Jones and Lincoln, 1972; Kingwell, 1974) there are the advantages of higher stocking density, less critical husbandry criteria and the elimination of high costs of energy for pumping water through tanks.

It has been amply demonstrated that turbot accept a pelleted diet. Fed on moist pellets, formulated and

produced by the Authority, the conversion efficiency has been improved to 50%. Recent introduction of a whole sprat diet, has indicated that a similar conversion can be achieved, and has enabled feeding costs to be reduced significantly in the ongrowing stages.

The first trials with hatchery-produced juveniles have shown their greater potential for growth compared to their counterparts of wild origin, with minimal differences in husbandry techniques being required. With turbot hatchery techniques now becoming significantly improved, it is considered that sufficient data will soon be available to allow the farming of this species to be evaluated properly for commercial exploitation.

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Comparative Economics of Aquaculture in Cages, Raceways and Enclosures

R. A. Collins and M. N. Delmendo

Abstract

In the development of aquaculture methods throughout the world, knowledge about the economics of the various methods is essential. High density culture, such as in cages, raceways, and enclosures, is becoming more widespread and information about the economics is scattered and fragmented. The present study brings together the economic aspects of these methods of high density aquaculture.

Cages and raceways are intensive methods, *ie*, they require some environmental control, the fish are stocked at a high density, and virtually all the feed is provided from an outside source. However, culture techniques for enclosures may be either intensive or extensive. If species such as the planktophagic milkfish are stocked at a lower density and receive all their feed from autochthonous productivity, the method becomes extensive.

One species, the channel catfish (*Ictalurus punctatus*), was used in the economic evaluation of the three intensive methods, and the milkfish (*Chanos chanos*) was used in evaluation of enclosures as an extensive method. The data represent information obtained from numerous publications and personal experiences rather than from a single research project.

Raceways required the greatest amount of initial capital and cages required the least. Enclosures used on an extensive basis required the greatest amount of capital on an annual basis. Milkfish fry for initial stocking were less expensive on an individual basis than were catfish fingerlings, but because of high mortality milkfish fry represented a greater operational cost. Feed was by far the highest operational cost (55·5%) in intensive culture. Enclosure culture required more labour because of harvesting. Costs per kg of catfish with one crop per year were: cage US$ 0·71, raceways US$ 0·72, enclosures (intensive) US$ 0·47. With the two crops per year the costs per kg were: cages US$ 0·67, raceways US$ 0·67, enclosures (intensive) US$ 0·71, enclosures (extensive) US$ 0·47. Pumping water for raceways increased the cost/kg of fish US$ 0·07.

Estimates of income from all three aquaculture methods show favourable margins of profit (excluding pumping costs and taxes on net earnings).

Rentabilité comparée de l'aquaculture en cages, en raceways, et en enclos

Résumé

Pour améliorer les méthodes d'aquaculture dans le monde, il est essentiel d'en connaître les caractéristiques du point de vue de leur rentabilité. La pisciculture de haute densité, comme celle qui est pratiquée en cages, en raceways et en enclos se répand de plus en plus mais les informations que l'on possède sur leurs aspects économiques sont fragmentaires et dispersées. La présente étude rassemble les informations dont on dispose sur les aspects économiques des méthodes d'aquaculture de haute densité.

Les cages et les raceways sont des méthodes d'élevage intensif qui exigent par conséquent une surveillance étroite du milieu; d'autre part, les poissons sont réunis en grande quantité et leur nourriture provient presque entièrement de sources extérieures. Les techniques d'élevage en enclos peuvent être intensives ou extensives. Si des espèces comme les chanidés planctophages sont stockées en faible densité et qu'elles ne reçoivent d'autre nourriture que celle produite par le milieu, il s'agit d'une méthode d'élevage extensive

Pour évaluer la rentabilité des trois méthodes intensives, on s'est servi d'une espèce particulière, le poisson chat (*Ictalurus punctatus*), et on a utilisé des chanidés (*Chanos chanos*) pour évaluer la méthode d'élevage extensif en enclos. Les donnees presentees ici proviennent de nombreuses publications et d'expériences personnelles et non pas d'un seul projet de recherche.

Ce sont les raceways qui exigent les plus importants investissements, et les cages, les plus faibles. Utilisés pour un élevage extensif, ce sont les enclos qui exigent chaque année les dépenses les plus considérables. Les alevins de chanidés utilisés pour constituer le stock initial coûtent moins cher, par unité, que les alevins de poisson chat, mais étant donné leur taux de mortalité élevé, leur utilisation entraîne des frais d'exploitation plus importants. En ce qui concerne ces frais, c'est la nourriture qui en constitute la part essentielle (55,5%) lorsqu'il s'agit d'un élevage intensif. L'élevage en enclos exige une main-d'oeuvre plus importante étant donné les travaux auxquels oblige la récolte. Le coût du kilo de poisson chat, à raison d'une récolte par an, est le suivant: en cages US$ 0,71, en raceways US$ 0,72, en enclos (élevage intensif) US$ 0,47. A raison de deux récoltes par an, le coût par kilo est le suivant: en cages US$ 0,67, en raceways US$ 0,67, en enclos (élevage intensif) US$ 0,71, en enclos (élevage extensif) US$ 0,47. Le pompage de l'eau qu'exige l'utilisation des raceways augmente de coût du kilo de poisson de US$ 0,07.

Les évaluations des recettes tirées de ces trois méthodes d'aquaculture font ressortir des marges de profit favorables (coûts de pompage et taxes sur les recettes brutes non comptés).

Estudio económico comparativo de la acuicultura en jaulas, canales y recintos

Extracto

En el desarrollo de diversos métodos de acuicultura en todo el mundo, es esencial conocer bien los aspectos económicos de los distintos métodos. El cultivo a grandes densidades—por ejemplo, en jaulas, canales y recintos—está cada dia más extendido, y la información sobre sus aspectos económicos está muy dispersa y fragmentada. En este estudio se comparan los aspectos económicos de estos métodos de cultivo a grandes densidades.

Las jaulas y canales son métodos intensivos: es necesario cierto control del medio ambiente, los peces se siembran a grandes densidades y prácticamente todos los alimentos provienen de fuentes exteriores. En cambio, las técnicas de cultivo en recintos pueden ser intensivas o extensivas. Si se utilizan especies como el sabalote, que son plantófagas,

la siembra se hace con baja densidad y todos los alimentos de los peces son de origen autóctono, el método puede considerarse extensivo.

Para evaluar económicamente los tres métodos de cultivo intensivo se utilizó bagre de canal (*Ictalurus punctatus*), y para evaluar el valor de los recintos como método extensivo se utilizó el sabalote (*Chanos chanos*). Los datos reúnen información procedente de numerosas publicaciones y experiencias personales, en lugar que de un sólo proyecto de investigación.

El método que mayores inversiones iniciales de capital exige es el cultivo en canales, y el que menos, el cultivo en jaulas. El método que exige mayor cantidad de capital anual es el cultivo extensivo en recintos. El precio unitario de los jaramugos de sabalote para siembra inicial resultó menor que el de los jaramugos de bagre, pero debido a la elevada mortalidad del sabalote la adquisición de jaramugos representa un costo más elevado de operación. En el cultivo intensivo, el porcentaje más elevado de los gastos operacionales (55,5%) correspondió a los piensos. En el cultivo en recintos fue necesaria más mano de obra para la recolección. Los costos por kg de bagre, con un solo ciclo de producción al año, fueron: US$ 0,71 en jaulas, US$ 0,72 en canales, US$ 0,47 en recintos (cultivo intensivo). Con dos ciclos de cría al año, los costos por kg fueron: US$ 0,67 en jaulas, US$ 0,67 en canales, US$ 0,71 en recintos (cultivo intensivo), US$ 0,47 en recintos (cultivo extensivo). El bombeo de agua para los canales aumentó el costo por kg de pescado en US$ 0,07.

Los ingresos estimados con estos tres metodos de acuicultura muestran márgenes favorables de beneficios (excluidos los costos de bombeo y los impuestos sobre los beneficios netos).

1 Introduction

Economic comparisons of different methods of aquaculture on a global scale are difficult at best and must contain many uncertainties requiring a number of assumptions. Some principal problems causing the uncertainties are: (*i*) the many environmental variables; (*ii*) ecologically different species of fish; (*iii*) differences in social culture and economics in the various countries; and (*iv*) lack of adequate research data on some methods of aquaculture. However, at the present stage of development of aquaculture around the world, economic comparisons are much needed as an interim step in further development (Pillay, 1973). It is within this framework, *ie*, uncertainty opposed by need, that the authors have attempted economic comparisons of three high density methods of aquaculture: cages, raceways and enclosures.

Culture in cages and raceways is exclusively intensive, *ie*, it requires some environmental control, the fish are stocked in high density, and virtually all the feed is provided from an outside source. However, aquaculture in enclosures may be either intensive, extensive, or a combination of the two. If species such as the milkfish are stocked at a lower density and receive all their feed from autochthonous productivity, the method becomes extensive (Neal, 1973).

Arguments are put forth frequently about the advantages and disadvantages of the different methods of aquaculture. These arguments are often meaningless because proponents of a given method commonly advocate use of the method under a great variety of circumstances. Of course, no method is superior in all situations, and a method should be selected that best suits the conditions. For a given set of environmental conditions, the method selected should be the one that is most economical, provides the least risk of loss from environmental variables, and is compatible with other uses of an area.

Comparison of production costs for the three intensive methods revealed no important differences. Factors other than cost of production are more important in selecting between cages, raceways and enclosures for intensive culture. Enclosures used as extensive culture have much lower production costs, and could be used where high quality feeds are not available.

2 Basis of economic comparisons

Three tables of production costs, Tables I, II and III, were prepared for comparison of intensive culture by each of the three methods considered. One species, the channel catfish (*Ictalurus punctatus*), was used in each table in order to reflect more clearly differences in culture methods, rather than differences in species. The channel catfish was selected because: (*i*) it is a warm water, omnivorous species, and the vast majority of fish cultured for animal protein will be warm water species; (*ii*) much research data are available on this species for such factors as conversion rates, mortality, rate of growth, *etc*; and (*iii*) the authors' familiarity with the species.

The tables do not represent data from any one research project, but instead, were compiled from several published reports and personal experiences. Therefore, the tables represent generalized or hypothetical production costs, but all entries in the tables were based upon published facts in so far as possible. Table III dealing with intensive culture in enclosures was supported by less published information than either of the other tables.

Costs of most items included in the tables vary considerably from one country to another. Therefore, the method of arriving at each figure was shown in the tables so that they could be varied when modified for a particular country.

Feed conversions and growth rates were considered to be the same for each method because if water quality is approximately equal in each method the rates will be the same. As an example, rainbow trout cultured in raceways and cages in similar water produced virtually identical conversions of 1·54 (Collins, 1972; Ward, personal communication). A complete, 36% protein, pelleted feed was considered to be necessary for the intensive methods. An average of 32 days was the time allowed for doubling the weight of the fish (Collins, 1970 and 1971).

Such factors as feed conversion, growth rate, and mortality are as variable as the abilities and training of the persons responsible for aquaculture projects. Some persons lose all their fish and some lose less than 1%. Conversions vary from 1·25 to 4·0[1]. These variations are not inherent in the systems, but rather in the operators, so average values of 10% mortality and 1·6 conversion were selected as the results expected from knowledgeable and experienced aquaculturists (Arroyo, 1973).

There are various methods of calculating depreciation, amortization and interest rates. The method selected for the present report was amortization of capital items by dividing cost of the item by the number of years of life expectancy, and then this value was charged as an annual cost. The interest rate was 8% per annum, an average value most common in 1976. Interest was charged on amortized capital funds based upon the formula:

$$A = \frac{I \times C}{N^2} \Sigma K \text{ where:}$$

A = average interest charge if depreciation amount is saved from revenue in each year of operation
I = yearly interest rate
C = cost of capital item
N = life in years
K = 1 to N

[1] $\text{Conversion} = \frac{\text{total weight (kg) feed added}}{\text{net weight (kg) fish produced}}$

TABLE I
PRODUCTION COSTS OF 50 000 CHANNEL CATFISH IN CAGES
(160 DAYS AND 800 g WEIGHT AT HARVEST, NO COST FOR WATER)

	Initial costs US$	*Annual costs US$*	%
A. Capital costs			
1. Cages—50 × US$ 100, 3 years amortization	5 000	1 666	6·5
2. Service building—20 year amortization	5 000	250	1·0
3. Boat and motor—5 year amortization	1 500	300	1·2
4. Interest on amortized capital funds—8%/annum		548	2·1
	11 500	2 764	10·8
B. Operational costs			
1. Fingerlings at 30 g—50 000 × US$ 0·06		3 000	11·8
2. Feed—US$ 250/ton, 1·6:1 conversion, 58 tons		14 500	56·8
3. Labour—US$ 2/h			
(a) positioning and stocking cages 40 h			
(b) harvesting 80 h			
(c) daily feed—6 h/day × 160 960 h			
(d) maintenance 100 h		2 360	9·2
4. Mortality—10%, averaging 200 g/fish = 1 000 kg, cost of fingerlings plus feed		700	2·7
5. Transportation—US$ 0·07/km, 30 km/day, 160 days		336	1·3
6. Fuel—4 l/day, US$ 0·25/l		160	0·6
7. Handling equipment		100	0·4
8. Chemicals		100	0·4
9. Miscellaneous expense—5% of operational costs		1 063	4·2
10. Interest on operational funds 8%/annum, 3 months		446	1·8
		22 765	89·2
Grand Total		25 529	100·0
Production costs/kg		0·71	
C. Gross Income (Sale of 45 000 channel catfish of 800 g/fish or 36 000 kg at US$ 1·25)		45 000	
D. Net Income before tax		19 471	
Ratio to operational cost			76·0
Ratio to gross income			43·0

Using the above formula, A will equal interest on approximately 50% of C on long-term depreciation (20–25 years), and about 67% on short term (3 years). Interest was charged on half of the operational funds because all of these funds were not utilized for the entire period.

The cost of labour can vary considerably, even at the same rate per hour, depending upon the degree of mechanization. The figures used assume no sophisticated equipment beyond nets, buckets, scales and possibly a lift boom.

In the first analyses, Tables I, II and III, no cost for water was included so that comparisons under ideal situations could be made. For instance, the following situations could exist whereby waters owned by a government could be made available to stimulate the economy and produce animal protein: (*i*) water flowing from a dam could be utilized for raceway culture; (*ii*) reservoirs, estuary bays, irrigation canals and natural lakes could be made available for cage culture; and (*iii*) estuaries and shallow lakes could be used for enclosure culture.

Table IV, which gives production costs of extensive culture of milkfish (*Chanos chanos*) in enclosures in the Philippines, differs slightly in design from the three examples of intensive culture because the data were taken directly from a single source, Delmendo and Gedney (1974). Interest costs were added to the original data.

3 Analyses of production costs

3.1 *Capital costs*

Of the three basic culture methods considered in Tables I, II, III and IV, raceways required the greatest amount of initial capital and cages required the least amount. However, when the capital costs were amortized, enclosures used on an extensive basis had the greater capital costs per year (Table IV). The high initial capital costs of raceways could be changed by using earthen raceways instead of concrete, but the cost would simply be shifted from capital to maintenance and labour. The high annual capital cost of enclosures resulted from the use of expensive synthetic netting which had a relatively short lifetime. Research on more durable materials and better construction to produce more permanent types of enclosures could possibly reduce the high annual capital costs as well as maintenance.

3.2 *Operational costs*

3.2.1 *Fingerlings.* The cost of fingerlings was the same for the three intensive methods, but much higher for milkfish production by the extensive method even though the cost per individual was much lower. The reason for the high cost of milkfish fry was the high rate of mortality [57% average as shown by Delmendo and Gedney (1974)]. This mortality rate could be reduced by better fry production techniques, handling and transportation methods and by disease and parasite control. All fingerling and fry costs probably would be reduced if an established, steady market was available to the producer.

3.2.2 *Feed.* The cost of feed for all three intensive methods was the greatest annual production cost of all items considered (average 55·5%, a fact which has been reported by

TABLE II
PRODUCTION COSTS OF 50 000 CHANNEL CATFISH IN RACEWAYS
(160 DAYS AND 800 g WEIGHT AT HARVEST, NO COST FOR WATER)

	Initial costs US$	*Annual costs US$*	%
A. Capital costs			
1. Land—2 ha, 20 year payout	2 000	100	0·4
2. Construction of 8 concrete raceways—25 year amortization[1]	40 000	1 600	6·2
3. Service building—20 year amortization	5 000	250	1·0
4. Interest on amortized capital funds, 8%/annum		1 958	7·6
	47 000	3 908	15·2
B. Operational costs			
1. Fingerlings at 30 g—50 000 × US$ 0·06		3 000	11·6
2. Feed—US$ 250/ton, 1·6·1 conversion, 58 tons		14 500	56·3
3. Labour US$ 2/h			
(a) stocking and harvesting 100 h			
(b) daily feed—4 h/day × 160 640 h			
(c) maintenance 100 h		1 680	6·5
4. Mortality—10% averaging 200 g/fish = 1 000 kg, cost of fingerlings plus feed		700	2·7
5. Transportation US$ 0·07/km, 30 km/day		336	1·3
6. Handling equipment		100	0·4
7. Chemicals		100	0·4
8. Miscellaneous expense—5% of operational costs		1 021	4·0
9. Interest on operational funds, 8%/annum, 3 months		429	1·6
		21 866	84·8
Grand Total		25 774	100·0
Production costs/kg		0 72	
C. Gross Income (Sale of 45 000 channel catfish of 800 g/fish or 36 000 kg at US$ 1·25)		45 000	
D. Net Income before tax		19 226	
Ratio to operational costs			75·0
Ratio to gross income			43·0

[1] 8 raceways 30 × 3 × 1 m Water 75 cm deep, 67 5 m³ per raceway, 70 kg fish/m³ at harvest (Piper, 1970)

TABLE III
PRODUCTION COSTS OF 50 000 CHANNEL CATFISH IN FENCED ENCLOSURES
(160 DAYS AND 800 g WEIGHT AT HARVEST, NO COST FOR WATER)

	Initial costs US$	*Annual costs US$*	%
A. Capital costs			
1. Fence 5 ha, 4 year amortization	8 000	2 000	7 3
2. Service building—20 year amortization	5 000	250	0·9
3. Boat and motor—5 year amortization	1 500	300	1·1
4. Interest on amortized capital funds—8%/annum		682	2 5
	14 500	3 232	11·8
B. Operational costs			
1. Fingerlings at 30 g—50 000 × US$ 0·06		3 000	10·9
2. Feed—US$ 250/ton, 1·6·1 conversion, 58 tons		14 500	53 0
3. Labour—US$ 2/h			
(a) stocking 20 h			
(b) daily feeding—5 h/day × 160 800 h			
(c) maintenance 100 h		1 840	6·7
4. Harvesting—US$ 0·05/kg		1 800	6·6
5. Mortality—10% averaging 200 g/fish = 1 000 kg, cost of fingerlings plus feed		700	2·6
6. Transportation—US$ 0 07/km, 30 km/day		336	1·2
7. Fuel—4 l/day, US$ 0·25/l		160	0·6
8. Handling equipment		100	0·4
9. Chemicals		100	0·4
10. Miscellaneous expense—5% of operating costs		1 127	4·1
11. Interest on operational funds, 8%/annum, 3 months		473	1·7
		24 136	88·2
Grand Total		27 368	100·0
Production costs/kg		0·76	
C. Gross Income (Sale of 45 000 channel catfish of 800 g/fish or 36 000 kg at US$ 1·25)		45 000	
D. Net Income before tax		17 632	
Ratio to operational costs			64·0
Ratio to gross income			38·1

numerous authors (Pillay, 1973; Shehadeh, 1974). Feed costs are difficult to reduce because the ingredients are used in large quantities in many types of feed and the prices fluctuate with world markets. In 1973, the cost of feed ingredients doubled and tripled on the world market causing many profitable aquaculture operations to become unprofitable. Moreover, good formulations of feed are essential because the fish receive only what is provided by the culturist. Formulations using locally produced ingredients, including lower quality fish, could reduce costs to some extent, but more research is needed in this area. Extreme care should be taken by the culturist to keep the conversion as low as possible, since feed is such a large percentage of the total cost (Palfreman, 1973).

The extensive method of culture using plankton feeders and herbivores avoids the high cost of feed, but such a method can be used profitably only in waters of high productivity. Extensive culture in enclosures can serve two purposes, both important in the world today—the production of animal protein and the reduction of organic pollution. Many of the the highly productive waters of today are productive because of pollution by organic wastes, and if the pollution is not too great, extensive fish culture could reduce the pollution and aid in recycling materials. Much money is spent on pollution control and it is not unreasonable to propose that some of those funds be applied to aquaculture operations to make them more viable enterprises.

3.2.3 *Labour.* Labour was more costly in enclosure culture than in either cage or raceway culture, principally because of harvesting costs. Harvesting costs in enclosures were comparable to those in ponds (Delmendo and Gedney, 1974; Greenfield, 1970). Research has not yet provided the industry with a satisfactory alternative to the time-honoured method of using a seine to harvest fish from relatively large bodies of water.

One aspect of labour was not included in this report, namely that required for guarding the fish from thieves. This omission may not be justified, based upon reports from virtually every country. Theft of fish that are easy to catch seems to be common to nearly all societies.

Labour for the intensive methods shown in Tables I, II and III cannot be compared equally with that for extensive culture in enclosures shown in Table IV because the rate of pay was much lower in the latter case.

3.2.4 *Miscellaneous items.* Miscellaneous or smaller expenses are quite variable depending upon a variety of circumstances which may exist in any particular country. However, these variable items do not contribute a large percentage to the overall cost of an aquaculture operation.

3.2.5 *Production costs per kilogramme of fish.* Under proper management with no cost for water, the costs of producing fish by the various methods are shown in Table V. If rental of water should be charged at the rate of 5% of the fish produced (Mathis, 1970), the cost becomes US$ 0·75 for cages, US$ 0·76 for raceways, and US$ 0·80 for intensive enclosures. In the data from Delmendo and Gedney (1974) (Table IV), the licence or rental fees for water amounted to 1·6%, which was included in the figure of US$ 0·47/kg (the costs were based upon two crops per year).

3.3 *One crop versus two crops per year*

For fish culture in tropical and subtropical climates, two

TABLE IV
PRODUCTION COSTS OF 200 000 MILKFISH IN FENCED ENCLOSURES WITH TWO CROPS PER YEAR AND AVERAGE WEIGHT OF 460 g AT HARVEST

	Initial costs US$	*Annual costs US$*	%
A. Capital costs			
1. Fence—10 ha, 4 year amortization	11 500	2 875	15·0
2. Building and boat—5 year amortization	3 450	690	3·6
3. Interest on amortized capital funds—8%/annum		740	3·8
	14 950	4 305	22 4
B. Operational costs			
1. Fingerlings—200 000 at US$ 0·023		4 600	24·0
2. Feed		828	4 3
3. Harvesting costs		1 288	6·6
4. Salaries for 4 caretakers		1 325	6·8
5. Mortality—57% of total fingerlings of 113 000 × US$ 0·023		2 599	13 6
6. Marketing costs		690	3·6
7. Licence fees		345	1·6
8. Administrative costs		1 150	6·0
9. Contingency and maintenance		1 495	7·7
10. Interest on operational funds, 8%/annum, 6 months		469	2·4
		14 789	77 6
Grand Total		19 094	100·0
Production costs/kg		0·47	
C. Gross Income (Sale of 87 000 milkfish of 460 g/fish or 40 000 kg at US$ 1·00)		40 000	
D. Net Income before tax		20 906	
Ratio to operational cost			104·2
Ratio to gross income			50·2

Source: Delmendo and Gedney (1974) based upon exchange rate of US$ 1·00 = PPs. 10, 15% inflation added

crops per year should be common. Temperate climates also provide for double cropping if a cold water species is utilized in the colder months (Collins, 1972). Double cropping would be economically advantageous because the capital costs are fixed and only operational costs need to be repeated for the second crop. Table V shows the production costs of one crop versus two crops per year.

TABLE V
PRODUCTION COSTS/KG OF CHANNEL CATFISH CULTURED IN CAGES, RACEWAYS AND ENCLOSURES PRODUCING ONE CROP VERSUS TWO CROPS PER YEAR

	One crop per year US$	*Two crops per year US$*	*Percent Difference*
Cages	0·71	0·67	5·6
Raceways	0·72	0·67	6 9
Enclosures	0·76	0·71	6·6

TABLE VI
PRODUCTION COST FOR PUMPING WATER INTO RACEWAYS (7M LIFT)

	Initial costs US$	*Annual costs US$*
A. Capital costs		
1. Pump and electric motor, 20 year amortization	2 500	125
2. Reservoir, 20 years payoff	750	38
3. Interest on amortized capital funds at 8%/annum		137
	3 250	300
B. Operational costs		
1 Electricity, pumping 6 056 l/ minute[1]		2 000
2 Maintenance—10% of cost of pump and motor		250
		2 250
Grand Total		2 550
Cost/kg of fish produced		0·07

[1] Cost of kWh plus US$ 90/month minimum charge for six months (Brewer, personal communication)

TABLE VII
ESTIMATED INCOME FROM INTENSIVE CULTURE OF CHANNEL CATFISH IN CAGES, RACEWAYS, AND ENCLOSURES, AND EXTENSIVE CULTURE OF MILKFISH IN ENCLOSURES

	Income (US$)		*Ratio of net income (before tax)*	
	Gross	*Net before tax*	*Operational Cost (%)*	*Gross Income (%)*
Cages[1]	45 000	19 471	76	43·0
Raceways[1]	45 000	19 226	75	43·0
Enclosures[1]	45 000	17 632	64	38·1
Enclosures[2]	40 000	20 906	104 2	50·2

[1] 160 day rearing period
[2] one year rearing cycle

3.4 *Economics of pumping water for raceways*

It has been proposed that culture in raceways, where all the water is pumped, is economically feasible (Chapman, Chesness and Mitchell, 1971). If the cost of pumping water is added to the data in Table II, the cost of production is increased US$ 0·07/kg or 10% as shown in Table VI. If water should be pumped from deep wells, the cost would be higher.

3.5 *Estimated income*

The approximate incomes from the three aquaculture methods show that all of them are fairly profitable activities (Table VII). The basis of calculation for income from channel catfish reared in cages, raceways and enclosures is US$ 1·25/kg, while the price of milkfish is US$ 1·00/kg at the site of production.

4 Conclusions

Comparisons on a cost of production basis of the three intensive methods of aquaculture, cages, raceways and enclosures, revealed no important differences. Therefore, in selecting one of these aquaculture methods, characteristics other than cost of production are more important. Within the economic considerations, the most important differences were the amount of initial capital required and labour costs for harvesting. Assuming the proper water conditions to be available for any of these methods, the method selected should be decided as follows: (*i*) if abundant capital is available and labour is expensive, raceways should be used; (*ii*) if little capital is available and labour is moderately inexpensive, cages should be selected; and (*iii*) with moderate capital and the least expensive labour, the situation is best suited for use of enclosures.

Estimates of income obtainable from intensive aquaculture in cages, raceways and enclosures as well as extensive culture in enclosures show favourable margins of profit. With further improvements of technology in the latter method, particularly in the reduction of fish seed mortality rates, the income structure of this activity would be greatly improved.

Extensive culture in enclosures is a method that lends itself best to situations where there are highly productive shallow water, inexpensive labour, and a lack of modern technology and equipment for manufacturing complete feeds. Whether or not complete feeds are available, if highly productive shallow water is available, extensive culture in enclosures is a relatively inexpensive method of producing fish.

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Chapter VII Wastes and Use of Recirculating Water in Aquaculture

Recycling of Wastes Through Aquaculture, and Constraints to Wider Application

G. H. Allen and B. Hepher

Abstract
Modern societies are forced to use water supplies that contain a large percentage of water previously used by man, *ie* 'waste waters'. Although the role of aquatic systems, such as fish ponds, for wastewater treatment has been neglected, they may have utility in many areas. The use of waste products to fertilize ponds can increase the growth and production of fish, and fish may improve the waste treatment capacity of pond systems.

Examples are given of how existing fish culture systems reduce BOD in waste waters under different conditions: with pretreatment of waste water, with dilution, with pretreatment and dilution, and with no treatment. Improved waste treatment can provide: an increase in phytoplankton, a removal of nutrients and an increase in the rate of disinfection. Meanwhile, benefits to fish culture from wastewater fertilization include increase in yields of fish and natural fish foods.

Restraints on wastewater fish culture may include: unsatisfactory dissolved oxygen levels in ponds; presence of toxic materials in waste waters; presence of unacceptable tastes and odours in fish; presence of parasites and diseases; various problems of public health; difficulties of satisfying pond effluent standards; and meeting public acceptance of the practice.

Successful wastewater aquaculture requires much information on and an understanding of many processes and disciplines, *eg* , the physico-chemical dynamics of pond environment in relation to the physiological requirements of a cultivated species. Other examples include: knowledge of pond management techniques, genetic considerations, the role of algae, *etc.*

The integration of aquaculture, agriculture, public health and water pollution control is a difficult but necessary task requiring a co-operative inter-disciplinary approach. From the standpoint of fish culture, further documentation of the lesser potentials of zoonoses through fish, and studies such as the economic benefits of wastewater aquacultural systems would improve the status of using such a system. The role of human pathogens in such systems, both temperate and tropical, must also be studied.

Le recyclage des eaux résiduaires dans l'aquaculture et les limites à l'élargissement de son application
Résumé
Les sociétés modernes sont contraintes de recourir à des approvisionnements d'eau qui contiennent un pourcentage élevé d'eau précédemment utilisée par l'homme, à savoir "d'eaux usées". Bien que l'on ait négligé le rôle des systèmes aquatiques, tels que les étangs de pisciculture, pour le traitement des eaux usées, ils peuvent avoir une utilité dans de nombreuses régions. L'emploi de déchets pour fertiliser les étangs peut stimuler la croissance et la production de poisson, et le poisson peut améliorer la capacité de traitement des déchets des systèmes aquatiques.

Le document donne des exemples de la manière dont les systèmes piscicoles réduisent la DOB des eaux usées dans diverses conditions: par prétraitement, par dilution, par prétraitement et dilution et sans traitement. L'amélioration du traitement des déchets peut procurer un accroissement du phytoplancton, une élimination des nutriments et une élévation du taux de désinfection. Par ailleurs, la fertilisation par les eaux usées profite à la pisciculture en accroissant les rendements en poisson auquel elle procure un aliment naturel.

Parmi les limites au recyclage des eaux usées dans la pisciculture figurent: un taux d'oxygène dissous insuffisant dans les étangs; la présence de substances toxiques dans les eaux usées; la présence de saveurs et d'odeurs inacceptables dans le poisson; la présence de parasites et d'affections; divers problèmes de santé publique; la difficulté de satisfaire aux normes fixées pour les affluents dans les étangs; et l'acceptation de cette pratique par l'opinion publique.

Pour réussir, le recyclage des eaux usées dans l'aquaculture nécessite une ample information et une connaissance approfondie de nombreux processus et de maintes disciplines, par exemple, la dynamique physico-chimique de l'écologie des étangs du point de vue des besoins physiologiques d'une espèce de culture. Parmi d'autres exemples, citons encore la connaissance des techniques de l'aménagement piscicole, les considérations génétiques, le rôle des algues, *etc.*

L'integration de l'aquaculture, de l'agriculture, de la santé publique et de la lutte contre la pollution des eaux est une tâche difficile mais nécessaire, qu'il faut aborder dans un cadre coopératif et interdisciplinaire. Du point de vue de la pisciculture, l'utilisation d'un tel système beneficierait d'une documentation sur les dangers reduits de transmission des zoonoses par l'intermédiaire du poisson, et des études sur les avantages économiques des systèmes aquicoles fondés sur le recyclage des eaux amélioreraient les perspectives d'un recours à de tels systèmes. Il convient également d'étudier le rôle des agents pathogènes de l'homme dans ces systèmes que ce soit en climat tempéré ou tropical.

Reciclaje de desechos mediante la acuicultura e impedimentos que se oponen a una mayor utilización de este sistema
Extracto
Las sociedades modernas están obligadas a aprovechar los suministros de agua que contienen un gran porcentaje de aguas utilizadas previamente por el hombre, es decir, "aguas residuales". Aunque de ordinario se ha pasado por alto la función de los sistemas acuáticos (por ejemplo, los estanques piscícolas) para el tratamiento de las aguas de descarga, en algunas zonas pueden resultar útiles. El empleo de productos de desecho para fertilizar los estanques puede aumentar el crecimiento de los peces y la producción piscícola, y los peces, a su vez, pueden mejorar la capacidad de tratamiento de desechos de los estanques.

Se dan ejemplos de como los sistemas actuales de piscicultura reducen la demanda biológica de oxigeno (DBO) de las aguas residuales en diversas condiciones: con tratamiento previo de las aguas residuales, con dilución, con tratamiento previo y dilución, y sin ningun tratamiento. Un mejor tratamiento de los desechos puede permitir aumentar el fitoplancton, extraer sustancias nutrientes y aumentar el ritmo de desinfeccion. Por otro lado, entre los beneficios que la fertilización con aguas residuales aporta a la piscicultura figuran el aumento del rendimiento de los peces y el aumento de los alimentos naturales para los peces. Entre los obstáculos que se oponen a la pisciultura en aguas residuales figuran, niveles no satisfactorios de oxigeno disuelto en los estanques; la presencia de sustancias tóxicas en las aguas residuales; la presencia de sabores y olores inaceptables en los peces; la presencia de parásitos y enfermedades; varios problemas de salud pública; la dificultad de cumplir con las normas relativas a los efluentes de los estanques; y la aceptación de este sistema por parte del público.

Para que la acuicultura en aguas residuales sea fructífera es necesario disponer de mucha información y entender diversos procesos y disciplinas, como por ejemplo, la dinámica físico-química del medio ambiente de los estanques en relacion con las necesidades fisiologicas de la especie cultivada. Es necesario igualmente conocer las tecnicas de manejo de los estanques, diversas consideraciones geneticas, la función de las algas, *etc.*

La integración de la acuicultura, la agricultura, la salud pública y el control de la contaminacion de las aguas es una tarea difícil, pero necesaria, que es preciso afrontar interdisciplinalmente. Para mejorar las posibilidades de aplicación de este sistema sería útil disponer de documentación sobre el menor potencial de transmisibilidad de las zoonosis a través de los peces y realizar estudios sobre los beneficios económicos de la acuicultura en aguas residuales. Es necesario estudiar también la función que tienen en esos sistemas, tanto templados como tropicales, los agentes patógenos que afectan al hombre.

1 Introduction

1.1 *Scope of Paper*

Many societies have been able to treat water as an unlimited, essentially 'free', generally 'pure', 'natural' resource. Modern industrial societies are now forced to use water supplies that contain a large percentage of water previously used by man, *ie*, 'waste waters'. Such unavoidable uses of waste waters include that for his domestic needs. This includes his drinking water, for which the use of waste water is now so large in some areas that official recognition of the fact has occurred (Shuval, 1977). Probably in subconscious reaction to this fact, uses of waste water coming under permit from wastewater control and other public

authorities, are becoming immersed in a sea of rules, regulations, policies, and laws (see Kildow and Huguenin, 1974; Huguenin and Kildow, 1974, for a review of the situation in the United States).

Purposeful uses of waste waters will continue to grow. The recovery of valuable products carried by waste waters for plant growth (*eg*, phosphorus, nitrogen, and other elements) is no longer an esoteric matter (Pimental *et al*, 1973). In arid areas the water itself is especially valuable for irrigation and aquaculture.

Aquatic systems to dispose of domestic wastes can probably be associated with the most ancient tribal groupings, since such groupings tended to associate with water courses. With the coming of the industrial revolution, sophisticated mechanical systems of wastewater treatment were developed. In disposal of effluents, the principle of dilution in water is still an integral part of the design of systems for wastewater treatment. The utility, however, of aquatic systems, such as ponds for wastewater treatment, has been neglected, perhaps in part for psychological reasons (McGauhey, 1964) and in part because of mismanagement due to their high shock resistance (Stander *et al*, 1970). Nevertheless, in areas with cheap land, limited capital resources, or water shortage, pond systems of water purification (*eg*, Parker, Jones and Taylor, 1950; Parker, 1973; Folkman, Meiring and Kremer, 1973) have had extreme utility. Reclamation of waste water through high-energy technologies, such as desalinization, is now becoming more viable economically than water production. Aquaculturists have used waste products, including those of man, to fertilize ponds to increase growth and production of fish since antiquity (Lin, 1954; Prowse, 1962; Borgese, 1975). Recent studies (Schroeder, 1975; Carpenter, 1974; Coleman *et al*, 1974; Goldschmidt, 1970) have indicated that fish improve the waste treatment capacity of pond systems. Similarly, there has been an increased interest in using waste water in modern aquaculture. A recent conference (Carpenter, 1974) stressed the use of waste waters in food production, while another (D'Itri, 1977) emphasized food-producing biological systems as wastewater purification schemes. Sanitary engineering conferences seem to be giving more stress to aquatic systems (*eg*, the International Conference on Biological Water Quality Improvement Alternatives, University of Pennsylvania, March 1975). It can be seen that wastewater aquaculture is a very broad, interdisciplinary subject. Within the assigned limits of this paper, the scope will be further restricted to that of wastewater fish culture, and to those principles believed to be of importance to the practical utilization of waste waters to fertilize fish ponds. Some constraints on this practice from a fish culture viewpoint, and some immediate research needs, will also be discussed.

1.2 *Recent literature*

Reports published primarily in English prior to (roughly) 1965 on the use of sewage in fish culture were listed by Allen (1969), and a review on sewage fertilization based on this literature was published by Allen (1972). A large literature on the effects of waste waters on fish life exists in the water pollution control and sanitary engineering literature which has been reviewed by Tsai (1975). This latter review, based on both fresh- and saltwater regimes, was undertaken as a basis for considering the potential use of domestic waste water in aquaculture. The references listed by Tsai, plus those in Hepher and Schroeder (1974, 1977), will provide a major portion of the data published since 1965 on sewage utilization in fish culture, exclusive of Asia and eastern Europe. An early review of sewage as one method of fertilizing fish ponds (Mortimer and Hickling, 1954) has been out of print, but their section on sewage in fish culture was appended to Allen (1972). Some additional references are listed in proposals for wastewater use in fish culture, based on practical knowledge and published material, by Lin (1974) and Donaszy (1965). Papers by Ghosh, Banerjee and Rao (1973) and Ghosh, Rao and Banerjee (1974) were not available for review.

2 Classification of wastewater fish culture systems

Tsai (1975) grouped wastewater fish culture systems according to methods of feeding fish. Hepher and Schroeder (1977) presented a classification system using methods of reducing the biological oxygen demand (BOD) of the waste water. This approach directs attention to a major limiting factor controlling the use of waste waters for fertilizing ponds. Some examples of how existing fish culture systems reduce BOD in waste waters are tabulated on page 480, using Hepher and Schroeder's scheme.

3 Benefits from wastewater fertilization

The benefits to be derived from the utilization of waste waters may be considered under two categories: those related to fish culture, and those related to wastewater treatment.

3.1 *Benefits to fish culture*

3.1.1 *Increase in fish yields.* Considerable historic evidence exists to illustrate the increase in fish production using waste water (Table I). More recent results reported by Hepher and Schroeder (1977) showed a 70% greater yield of fish with a 40% reduction in supplemental feed required to grow a unit weight of fish in organically fertilized (manured) commercial ponds as compared to ponds fertilized with inorganic chemicals (Table II). The significance of these latest results is not only in the percentage increase, but also in the absolute increase in yield (about 3 500 kg/ha over an 8 month period). Hepher and Schroeder (1977) also report unpublished data from experiments at the Fish and Aquaculture Research Station, Dor, Israel, on use of fluid cowshed manure only to produce net fish crops, based on extrapolated values, of about 4 900 kg/ha. These results exceed commercial production rates in ponds using supplemental feed and inorganic fertilizers.

3.1.2 *Increase in natural fish foods.* Wastewater-fertilized ponds produce high yields because of the increase in natural foods produced by these wastes (Sharp, 1974; Wirshubsky and Elchuness, 1952; Schroeder, 1975). Several recognizable major processes are involved in this increase in actual fish food supply (Hepher, 1975).

(*i*) Nitrogen and phosphorus, and trace elements, stimulate phytoplankton production in the same manner as inorganic fertilizers. This process is limited by autoshading (Hepher, 1962).

(*ii*) The smaller particles of organic waste in waste water provide a direct source of food to zooplankton and benthos. This process is not light-limited as is the production of

2.1 *Pretreatment of waste water*

Author	*Pretreatment system*	*Comments*
Mayenne (1933)	Cascading water through six ponds in series	Carp could be grown in the last three units, and only during summer
Hey (1955)	Two-stage trickling filters with final sedimentation	*Tilapia* were successfully reared after ponds were cleaned and a non flow-through pond system used
Wolny (1962)	Activated sludge process	Fish increased oxygen levels in all ponds used, but the best improvement occurred in stagnant ponds
Coleman *et al* (1974)	Forced-air system in first two units of a six-cell pond system	A variety of fish occurred in all cells. High effluent quality

2.2 *Dilution of waste water*

Author	*Pretreatment system*	*Comments*
Demoll (1926)	Primary treated water diluted 1 to 4–6 with fresh water	Summer rearing of carp most successful operation
Vaas (1948)	Septic tank water mixed 1:3 with river water	High yields without supplemental feeding; fish losses no greater than in non-sewage ponds

2.3 *Pretreatment and dilution*

Author	*Pretreatment system*	*Comments*
Allen and Dennis (1974)	Sedimentation, aeration, and oxidation pond treatment. Effluent mixed 1:1 with sea water	High-quality waste water plus dilution needed for rearing physiologically sensitive salmon and trout. Pilot-plant operation
Ryther (1975)	Secondary effluent into seawater ponds injected with selected algal cultures; algae fed to bivalves	Bivalve faeces require treatment. Flatfish used in terminal units. Pilot-plant operation

2.4 *No treatment of waste water*

Author	*Pretreatment system*	*Comments*
Bose (1944) Nair (1944) Basu (1949)	Preliminary settling and partial stabilization in channel leading to fish ponds. Waste water introduced monthly at ratio of 1 part new water·3–4 parts stabilized fish-pond water	High fish production, high demand Fish harvested and sold at pond site
Hepher and Schroeder (1974, 1975)	Fish ponds filled with fresh water; domestic waste waters from rural communities (Kibbutzim) fed into ponds; high dilution rates	Wastewater supply to area (Israel) low, thus generally waste water replaces pond losses from seepage and evaporation. Often some stabilization of waste water in pipes and ditches

TABLE I

SUMMARY OF EXAMPLES OF FISH PRODUCTION OBTAINED FROM FISH PONDS USING SEWAGE AS A SOURCE OF FERTILIZER (FROM HICKLING, 1962)

Location	*General nature of facility and fish culture operation*	*Levels of fish production*	*Production as g/m²/year*	*Author*
Munich	Low BOD sewage processed through fish ponds, with no supplemental feeding of common carp fingerlings grown over about a 7 month period	560 kg/ha	56	Not specified
Berlin	Fish ponds watered from Berlin sewage fields, with foddering of fish	850–1 050 kg/ha over the period 1953–55	86–106	Schaperclaus
Negev Desert	A 1 ha storage reservoir receiving domestic waste waters at about 600 gal/day. No foddering	3 700 kg from continuous netting, 1954–55	376	Sarig
Java	Effluent from a domestic septic tank diluted 1:3 with fresh water. No foddering	3 000 kg/ha/year	300	Vaas
Calcutta	Partially clarified sewage effluent used to produce large crops of fish and rice in alternate years	Data on fish production not given but income from fish much higher than income from rice	—	Nair
Bengal	Sewage-manured fisheries	672 kg/ha/year	67	Alikhuni

TABLE II

FISH PRODUCTION AND FEED CONVERSION FACTORS FOR COMMERCIAL ISRAELI FISH POND UNDER VARIOUS FERTILIZATION SCHEMES (FROM HEPHER AND SCHROEDER, 1977)

	Fertilization schemes					
	Ammonia and phosphate only		*Waste water only*			*Fluid cow manure (plus ammonia and phosphate)*
Pond area (ha)	1·4	2·2	0·7	1·0	1·0	2·0
Fish yield (kg/ha/8 months)	4 700	4 700	8 000	8 600	8 100	7 500
Conversion factor (kg food/ kg fish yield)	1·8	1·6	0·9	1·0	0·8	1·1

organic matter by phytoplankton. Direct utilization of larger particles by fish undoubtedly also occurs. Bacteria on the smaller particulate matter appears to be the major source of nutrients (Mann, 1972).

(*iii*) The direct use of soluble organic material in natural waters by phytoplankton or zooplankton seems likely. This concept has had lively scientific debate for years (Putter's Hypothesis). Recent work in fresh waters (Wuhrmann, 1968) and marine areas (Conover, 1966) continues to suggest this as a pathway to organic production of fish foods from dissolved organic constituents in waste and natural waters alike.

In addition to the quantity of natural foods in wastewater fish ponds, qualitative factors are involved. The more the natural food, the greater the likelihood of providing for the nutritional deficiencies that can often appear in commercially prepared supplementary feeds. The increase in natural fish foods from wastewater fertilization will be reflected in a decreasing need for supplementary feeds (conversion factor, Table II), due to both the quality and quantity of natural foods provided.

3.2 *Improved waste treatment*

3.2.1 *Increase in phytoplankton.* There is considerable literature on the utilization of fish ponds as a wastewater treatment system (Allen, 1969, 1972) of which two major papers on early German systems were those of Demoll (1926) and Kisskalt and Ilzhofer (1937). The considerable use of aquaculture and agriculture systems for waste disposal in the Federal Republic of Germany has become a part of their sanitary engineering principles (Schulte, 1969). Wastewater-fertilized fish ponds undoubtedly function similarly to pond systems designed specifically for waste treatment (Oswald, 1973; Parker, 1973). Such pond systems operate primarily through bacterial and algal growth. Considerable controversy, however, exists in the sanitary engineering field over pond systems for wastewater treatment with the criticism arising principally because of the following factors:

(*i*) Algal cells produce a BOD in the effluent, which in the United States often exceeds proposed national (EPA) standards. In addition, algal concentrate nutrients need to be removed from effluent to meet discharge standards where prevention of eutrophication in receiving water is a public objective. No inexpensive way of removing algal cells from pond effluents has yet appeared, other than land application, or been demonstrated to a degree acceptable to wastewater authorities or engineers.

(*ii*) Ponds are operated improperly, often taking BOD loads beyond their design capacity, thus producing odours and poor quality effluents when the pond ecosystem fails (*ie*, ponds go septic; treatment system fails).

The second of these considerations is one that can be overcome by proper management and supervisory control (Folkman, Meiring and Kremer, 1973; Stander *et al*, 1970). The first consideration is of special interest to fish culturists and to fishery biologists. Phytophagous fish have the ability to remove algal cells from water (Prowse, 1969) and are employed in aquatic weed control (Sills, 1970). High yields in fish ponds using polyculture with 'Chinese carp' (Lin, 1974) (Table III) are largely due to phytophagous fishes. This concept of using fishes that feed on different segments of the plant and animal community in a pond is now being applied in high-technology approaches to wastewater aquaculture (Tenore, Brown and Chesney, 1974), and to wastewater treatment in an oxidation pond system (Coleman *et al*, 1974). Thus, phytoplankton, the major component in providing the basis of natural food chains in fish ponds, is also a major element in advanced biological treatment of waste waters. Basic understanding of these systems lies heavily in the field of plant physiology and ecology.

3.2.2 *Nutrient removal.* Tertiary treatment of waste waters (removing nutrients that cause eutrophication of receiving waters) by physico-chemical methods is now technically feasible but expensive. In fish ponds one generally finds high concentrations of calcium, high alkalinity and high pH values, all factors associated with high fish production. These are the same factors which are involved in the removal of phosphates from pond water (Hepher, 1958, 1977). This same chemical system is important in phosphate removal in oxidation ponds (Rohlich, 1964). Huge amounts of phosphorus are thus bound up in pond muds, plants, and in any level of the biotic pyramid feeding on pond plants. A second major nutrient in eutrophication, nitrogen, can be removed in a high degree from waste water treated in well designed pond systems using fish (Coleman *et al*, 1974). Most nitrogen under high pH conditions is transformed to a gaseous NH_3 and escapes to the atmosphere. Nitrate ends up in plants but again must be removed because the decay of the plants builds up nitrates in the pond water. Again harvesting the plants and animals removes this material along with phosphorus. This is especially important with respect to effluents discharging into marine areas where phytoplankton appears nitrogen-limited, not phosphorus-limited as in fresh waters (Ryther and Dunstan, 1971). Thus, removal of material anywhere in the plant-animal biotic web removes nutrients and is thus a tertiary wastewater treatment system. It is possible the nutrient drain could be improved by harvesting crustaceans, such as amphipods, to produce products using chitin (Pariser and Bock, 1972).

TABLE III
FEEDING CHARACTERISTICS OF CHINESE CARPS (FROM LIN, 1974)

Scientific name	*Common name*	*General living area in pond*	*Feeding habits*
Hypophthalmichthys molitrix	Silver carp	Fast swimming in upper layers	Phytoplankton (down to 20 microns in size or less)
Aristichthys nobilis	Bighead	Slow moving in upper layers	Phytoplankton, zooplankton, suspended detritus
Mylopharyngodon piceus	Black carp	Bottom	Snails, mussels, crustacea
Ctenopharyngodon idella	Grass carp	Ubiquitous	Variable, but with ability to consume a wide variety of plant material

3.2.3 *Capacity for disinfection.* One of the more interesting effects of fish in aquatic systems is that of improving the oxygen regime (Schroeder, 1975) through their part in producing a 'self-designed, self-managed' more balanced ecosystem (Odum, 1977). Due to high photosynthetic rates, fertilized ponds have high DO and high (generally over 8·5) pH values, as previously mentioned.

Oswald (1973) reports that increasing DO and pH in an aquatic system increases the rate of disinfection of coliforms. The levels of coliforms in the Arcata wastewater fish ponds in California have also been low, often less than in the receiving waters (Allen, Busch and Morton, 1979). Janssen (1968, 1970) has warned that, although the current literature indicates negative findings on human bacterial diseases being transmitted through fish, these results must be confirmed through more intensive studies. The problem of zoonoses in general, let alone in aquaculture systems using fish, has only recently come under study. A major initial study in Oklahoma (Carpenter *et al,* 1974) showed virtually no human pathogens in cultured fish and drastic reductions in coliforms. Preliminary studies undertaken on small salmonids grown in domestic wastewater-fertilized ponds at Arcata showed faecal streptococci and other organisms associated with human diseases only in gut contents of the fish (Allen, Busch and Morton, 1979).

4 Restraints on wastewater fish culture

4.1 *Dissolved oxygen levels in ponds*

Highly fertile ponds, such as those receiving heavy organic loads and nutrients from waste waters, have healthy phytoplankton populations that produce sufficient oxygen during the day to meet BOD at night. With reduced oxygen production at night from reduced photosynthesis, oxygen levels become minimal prior to sunrise. When this minimum is below that required for the species, mortalities occur. Under minimal DO for the species cultured, the fish are also susceptible to stress from substances which they can otherwise tolerate under high oxygen levels (Doudoroff and Katz, 1950). Schroeder (1975) has developed a simple method of calculating the maximum amount of waste that can be added to a pond so that the expected morning DO for a pond system is not exceeded. (The procedure is outlined in Hepher and Schroeder, 1977). Aeration systems are now routinely used in commercial fish culture operations on a standby basis to ameliorate fish stress or losses during expected periods of low oxygen. Conversely, supersaturation of pond waters from phytoplankton photosynthesis may adversely affect both growth and survival of some species of fish (Doudoroff and Shumway, 1970; Warren, Doudoroff and Shumway, 1973).

4.2 *Toxic materials in waste waters*

Substances found in various waste waters that can be deleterious to fish, cover the wide range of wastes produced by modern man. Thus, there are many waste waters that cannot be used directly for fish culture. Even waste water in rural areas, or from non-industrial cities and towns, may cause problems to fish from biocides or detergents. Thus, even with a good prior knowledge of low potential toxicant levels in a potential aquaculture waste water, preliminary bioassay studies are needed to give additional indices to possible success (*eg,* Allen and O'Brien, 1967). Hepher and Schroeder (1977) used preliminary studies to indicate how the current levels of 'hard' detergents (ABS) in Haifa (Israel) sewage, even after treatment, would be a serious limitation to its use in fish culture. Each waste water must be evaluated on its own merits.

4.3 *Tastes and odours in fish*

Fish caught in natural waters frequently possess off-tastes and odours when caught in areas subject to discharges of raw wastes or from waste treatment facilities. Such tastes and odours arise mainly from industrial hydrocarbons. One might immediately suspect that any wastewater-grown fish would suffer the same fate. Some personal observations by various workers indicate that fish grown in well treated domestic wastes are equal to or even superior in taste or odour to non-wastewater cultivated fish. These observations have been made on wastewater-grown catfish (*Ictalurus*) (Carpenter, Quail Creek, Oklahoma), common carp (*Cyprinus carpio*) (Hepher, Israel), cut-throat trout (*Salmo clarki*) (Allen, Arcata, California), common carp (Reichenbach–Klinke, Munich, Federal Republic of Germany) and common carp (Scheuring, 1939, Munich). A major study using panels of experts and modern food tasting techniques available in food science and technology laboratories, is needed to either confirm or deny these personal experiences that might be challenged on the basis of bias or vested interest.

4.4 *Parasites and diseases*

The high pH and high oxygen levels in wastewater fish ponds could actually be producing quite disease-free environmental conditions as opposed to the expectation that such systems must encourage fish parasites, diseases, and pathologies, since zoonoses in wild fish from water with untreated or partially treated sewage have been well documented (Janssen, 1968, 1970). Carp reared in wastewater ponds in Germany and Israel suffer no greater problems than those in regular commercial ponds. Trout (*Salmo*) reared in the Munich system during the summer have suffered fungal infections, probably associated with high summer water temperatures. In general, the literature on wastewater-cultured fish has not reported heavy losses from fish diseases, something which would be inconsistent with the high production rates reported.

The bacteriocidal method by which natural waters supposedly destroy human pathogens is not known, but may be due to an 'obligate ectoparasite' living in sewage or soils (Janssen, 1970). An unknown therapeutic effect by wastewater–seawater mixtures was recorded in two-week bioassays on autumn chinook salmon fingerlings (*Oncorhynchus tshawytscha*) (Allen and O'Brien, 1967). In 1974, companion lots of four species of salmonids suffered disease problems in conventional hatcheries as opposed to lots reared in wastewater–seawater mixtures under high summer temperature conditions (20–26°C) (Allen, 1975). In Japan, the upper temperature limit for rainbow trout (*Salmo gairdneri*) cultured in nets in marine waters was reported as 22–23°C, with water over 23°C also inducing bacterial infections (Kawatsu, 1974). Preliminary studies on *Vibrio* (bacteria) disease in wastewater–seawater environments at Arcata have suggested again that some inhibitory effect on the virulence of this fish pathogen occurs in wastewater ponds (Allen, Busch and Morton, 1979).

There is a major need for research to elucidate the

possibility of a therapeutic effect on fish by culturing in certain types of wastewater systems.

4.5 *Public health problems*

Fish have not been shown to suffer from infections of *Salmonella, Shigella* or other enterobacteriacae that cause disease in humans or other warm-blooded animals (Janssen, 1970). They may, however, carry these infections if caught in the wild in polluted waters (Shewan, 1962). Janssen (1970) cites some cases where *Vibrio parahemolyticus* may have maintained itself in fish for a long period, whereas Guelin (1962) and Buttiaux (1962) concluded that such pathogens are carried passively, infecting only the gut surface which can be cleared by depuration. Recent studies of human pathogens in salmonids reared in Arcata wastewater fish ponds showed bacteria causing human infections only in the gut (Allen, Busch and Morton 1979). As in all water supply and wastewater processing systems, the fate of viral particles infectious to man requires a major commitment to supporting research on low-cost standard methods for identification and quantifying virus (Lund, 1977). Zoonoses problems associated with wastewater use in irrigation appear much more formidable than in fish ponds due to the fact that the pastured forms are warm-blooded, and because dispersion and decay is more difficult to study in non-turbulent sediments, sludges, and soils than in water (Kristensen and Bonde, 1977). As viral studies are expensive, placing fish culture units between the wastewater source and its application onto agriculture lands might be a manner in which co-operative schemes could reduce the costs of viral studies, while providing multiple benefits. Fish ponds, of course, can play a vital role in understanding the possible role of fish as reservoirs of human viruses about which we have little knowledge (Sonstegard, 1977).

4.6 *Pond effluent standards*

In the United States, and probably in other western countries with oligotrophic waters, fish culture operations are being scrutinized as to their contribution of BOD to receiving waters (Liao, 1970). In a study of the water quality problems of two California trout hatcheries, W. Winchester (personal communication) found a better quality effluent in a hatchery with more retention time of its water (settling basin and filtering system for water supply and a large pond for brood fish) than in a hatchery with a direct flow-through design. For many trout hatcheries, effluent sedimentation basins are being seriously considered as a potential adequate treatment facility. In west coast United States Pacific salmon hatcheries, intensive recirculating of the water to reduce the volume of effluent is employed. Tsai (1975) points out the efficiency of using a final pond for effluents in general. In water-short areas, fish farmers already recycle pond water back into the system (*eg*, the Israeli system at Coastal Plain Kibbutzim). Where increasingly stringent effluent standards in all waste discharges to oligotrophic waters seems imminent, the extra cost of meeting these standards will have to be carefully considered in plans for commercial wastewater culture operations. Where effluents are going into already existing fertile receiving waters, the enhancement of that environment by fish-pond effluents should not be overlooked by the fish culturist in dealing with water-quality authorities (see Oswald, 1973; McGauhey, 1964).

4.7 *Public acceptance*

Public need will probably determine the degree of public acceptance of wastewater-grown products in a particular area. The social, economic, and political considerations that influence human behaviour in this regard are very complicated (Huguenin and Kildow, 1974; Kildow and Huguenin, 1974; D'Itri, 1977). However, openness, candour, public education and public involvement appear the keys to public acceptance, at least in societies where consent of the governed plays a large role in public decisions. Of the literature reviewed by D'Itri, a report from California (Bruvold and Ward, 1972) was most intriguing in that 45% of those interviewed were initially prepared to accept recycled water for drinking and food preparation. In this study, two major reasons were reported by those opposing proposed uses of reclaimed water: (*i*) psychological repugnance, and (*ii*) lack of purity. It is possible that such high general support reflects a high level of education in that state, leading to a substantial understanding of ecological problems, and thus an ability to accept the new ideas of controlled eutrophication for public benefits.

Probably the most critical data to obtain public acceptance of wastewater-grown fish relate to the water's content of human pathogens. Depuration, such as is often used in cleaning bivalves before marketing, is the primary precautionary measure against transmission of human diseases in wastewater-reared fish (Hickling, 1962; Hepher, 1977). Undoubtedly some systematic study of the length of time human pathogens might stay in the intestinal tract of a fish placed in an environment clear of human pathogens would provide the type of data required. Obviously, initial development of re-utilization schemes not involving direct consumption of the product by human beings would allow time to develop background data on the entire zoonoses problem. If major disease pathways are found in these systems that cannot be cheaply and effectively controlled, then the original operation can be retained without loss of capital as the system can be turned to traditional culture operations.

5 Fish pond management

It is very difficult to identify all the information in the vast literature on fish culture, and specifically that of pond culture, that will prove useful to wastewater aquaculture. An example of understanding the physico-chemical dynamics of a pond environment in relation to the physiological requirements of a cultured species (carp) is that of Prowse (1966). Such understanding, coupled with application of modern principles of supplementing natural food chains with artificial fodders in high-technology commercial systems, through increased stocking rates (Hepher and Schroeder, 1977), should aid in maximum production in a pond fishery employing waste waters.

Experimental or pilot projects using polyculture as an advanced biological (tertiary) treatment system, deserve continued support since the public good is served by systems that can give increased water quality, and have the real potential for amortizing waste treatment costs by the sale of products. Studies at the Arcata wastewater treatment facility (Allen and Dennis, 1974; Allen and Carpenter, 1977) have been aimed at establishing the maximum growth and survival of juvenile salmonids in wastewater-fertilized seawater ponds without any artificial feeding. This has involved applying known pond management

techniques, such as aeration systems, pond bank modifications, pond bottom studies, and artificial reefs. Understanding the complexities in such aquatic systems will come slowly. Keys to understanding can come from the operational results of systems of controlled eutrophication (Ryther, 1977; Ball, 1977), but only tests of hypotheses developed in these pilot projects in commercial or commercial-type ponds will have direct application to commercial operations. Even here, the amount of variability to be expected in the most carefully controlled field experiments with ponds is probably much greater than previous results in the literature have indicated (Buck, Thoits and Rose, 1970). In addition, genetic considerations must be weighed since various strains of fish will react differently in different environments (Wohlfarth and Moav, 1969).

It would be of great value to propose general principles of wide application with respect to the subject. Each aquatic system, however, with its own species and strains of aquatic organisms, will develop its own unique problems. Some recent examples are listed in Table IV. These problems may be solved by applying techniques suggested in published information, but probably they will be solved by completely new applied research efforts directed at the specific fish culture problem encountered. This concept is illustrated by the organization of research support given to the fish farming industry in Israel, which is partly funded by the industry and partly by the revenue from fish produced by the research organization, as shown in Table V.

An important area of pond management that needs more attention is the role of algae. There is a strong need to interest botanists, especially algologists, to join research and management teams. We know that in nature there is algal succession by species and dominance by certain species. This phenomenon occurs even in what we consider highly controlled situations (*eg*, seasonal succession and dominance of algal species seemingly related to changes in incident solar radiation—Ryther, 1977). Dominance of undesirable algal populations in tropic fish ponds often can only be managed by complete draining of the pond and starting with new water (Prowse, 1966). A similar problem with algal dominance was found in Arcata ponds (Allen, 1975). Immediately after draining, two adjacent ponds were filled partially with pure sea water to maintain fish food items, with subsequent filling with a mixture of sea water and oxidation pond effluent. One pond developed a community which was always unsuitable for salmonids whereas the second pond developed a community in which four species of salmonids were successfully reared during summer months. Algal problems occurred in commercial Israeli carp ponds. It required almost a decade of research by Israeli botanists to understand the mechanism by which the brackishwater alga, *Pyremesium*, affected carp (Sarig, personal communication). This eventually allowed a simple method of controlling blooms of this alga with potential toxicity to carp by using an inexpensive commercial fertilizer (ammonium sulphate). It would seem likely that differences in primary productivity of the ponds produced much of the variability in fish production from the same pond in successive years found by Buck, Thoits and Rose (1970), and this would be due directly to the algal communities involved.

The subtleties involved in algal succession and domi nance may be too great in hypertrophic environments to understand or to control. It is possible that the idea of 'self-design' (empirical) approaches will have to be accepted, as it is in operation of trickling filters, sludge digesters, and activated sludge processes.

6 Integrated wastewater systems

Integration of aquaculture and agriculture is little understood or practised in much of the western world where high technologies often become frozen into administrative hierarchies. Aquaculture, agriculture, public health, and water pollution control tend to be empires apart, and interdisciplinary efforts are difficult to arrange (Allen, 1972; Hepher

TABLE IV
COMPARISON OF SOME RECENT PROBLEMS IN WASTEWATER AQUACULTURE AND FISH CULTURE SYSTEMS

Location	*Fish species*	*Problem and solution*
Israeli commercial fish farm	Common carp, *Tilapia*, silver carp	Fry on introduction to nursery ponds subject to heavy predation from invertebrates; short-term control of predators using a bromine compound (Schroeder, 1975a)
Quail Creek, Oklahoma, oxidation pond treatment system using polyculture	Catfish, minnows, *Tilapia*, others	Reduced feeding on phytoplankton during winter; search for coldwater adapted phytophagous fish (Allen and Carpenter, 1977
Woods Hole, Massachusetts, pilot project; tertiary biological treatment system. Cultures of algae to strip nitrogen with algae removed by bivalves	Flatfish in terminal units	Difficult to maintain phytoplankton species most utilized by oysters; determining minimal species combination and balance; system heating required in winter (Ryther, 1977)
Arcata, California, pilot project on pond culture of salmonids	Juvenile trout and Pacific salmon	Improving survival rates of chinook salmon in autumn by understanding exact cause of mortalities; establishing maximum stocking rates (Allen and Dennis, 1974)

TABLE V
SCHEMATIC ORGANIZATION OF ISRAELI TECHNICAL RESEARCH FIELD AND FISH-PRODUCTION EXPERIMENTS

General areas of technical investigations and expert personnel	*Field experiments in commercial or commercial-type ponds*
Food habits of selected fish species	Monoculture in communal ponds under different field situations to study the following factors:
Algal utilization efficiency in fish	(*i*) Clone (strain) species cultured
Genetics of breeding practices of carp	(*ii*) Stocking rate
Pond fertilization	(*iii*) Type of foods
Supplementary feeds	Polyculture to apply principles learned above to maximize production
Fish pathology and diseases	
Fish pond technology	
Product development	

and Schroeder, 1974, 1977; Carpenter, 1974; D'Itri, 1977).

A comparison was recently made of the production, economic return, and energy inputs of corn-belt farms in the United States between units employing inorganic fertilizers and pesticides, and those not using these techniques ('organic' farms) (Anon., 1975). Surprisingly enough, net income to the farmer was the same under either system, but the organic farms used two to three times less energy than the non-organic farms. (The organic farms grew chiefly corn, soybeans, wheat and oats, which were fed to cattle). There is no doubt that the income level of the organic farms could be raised further from increased production if suitable waste waters were made available to them (Bahr, 1977).

Shuval (1977), for certain uses of waste waters, listed a number of treatment processes required to meet given public health criteria. Waste water for crops not intended for direct human consumption needs at least primary treatment. For crops which will be eaten cooked, and for fish culture, primary and secondary treatment, plus sand filtration or equivalent polishing methods, were recommended. Thus, it appears that, where the fish pond acts as an improved oxidation pond, a high-quality effluent for such crops, plus a crop of fish provided by a fish pond in the system, seems an eminently practical system for consideration. Such integrated systems do exist throughout the world on informal or unauthorized bases. They probably do work without excessive public health risks, since no one has yet publicly challenged Stanford and Tuburan (1974) in their attempt to locate anywhere in the literature a public health problem associated with spray irrigation of waste waters receiving adequate secondary treatment. Most of the epidemics attributed to wastewater sources are from raw sewage gaining access to food eaten directly by man, or from contamination of a water supply distribution system by untreated sewage. Thus, controlled uses of waste waters seem to be successful in eliminating at least one of the seven sets of circumstances listed by Bryan (1974) whereby a person ingesting wastewater-contaminated foods can become ill. There is substantial reason to consider that heavily scrutinized wastewater-based food production schemes may be capable of supplying products safer from a public health standpoint than the normal flow of fish food products (Huguenin and Kildow, 1974). Such systems will have only scant chance of being considered in preliminary planning unless the regulatory authorities make it attractive to design engineers to analyse these systems at the same level as customary treatment systems (*eg*, activated sludge).

7 Discussion

Organic wastes produced by the normal metabolism of animals—whether they be in faeces from oysters, hippopotami, or man—provide direct or indirect sources of food for other plants or animals. In industrialized societies, short cycles back to man are broken because of the tremendous load of toxic materials he places in these waste waters. This in turn requires a tremendous effort either to purify water before using it or to purify waste waters before returning them to the environment. The regulation of toxic materials in water supplies has become both a national and international concern since it is a matter of survival. Two general methods of maintaining water quality by treating waste waters are employed. One is to collect all waste waters, domestic or industrial, for treatment at a central plant. The other method is to prevent the introduction of toxic materials into the domestic wastewater collection and treatment system. The former is the general practice today. The latter is the system that is required for allocating a true cost for products produced by entrepreneurs, as well as to allow fuller use of waste waters in all phases of food and fibre production, whether agricultural or aquacultural. Thus, the more rapidly societies place more emphasis on the recovery of noxious materials at the site of their production, the sooner will recovery operations be applied. This will result in waste waters being improved to acceptable quality levels, and re-use will become politically, biologically and economically feasible.

In the short term, effluents, primarily domestic in origin, should be utilized in schemes in which direct use by human beings is avoided (*eg*, fingerling fish for commercial growers, bait fish for sportsmen, juvenile stages in anadromous species, fish to be fed fresh or processed into meal for feeding species with high market value). This will allow time for additional work on the efficiency of fish ponds to process wastes in comparison to other accepted and established processes. Undoubtedly these comparisons with other systems will be based on the usual parameters used in sanitary engineering and wastewater control fields (coliforms, BOD, pH, colour, odour, *etc*). However, there are only a few instances of documentation of income from production in a wastewater aquaculture system. Until this is done, a complete cost-benefit analysis cannot be made. Thus, projects involving interdisciplinary scientific fields (*eg*, aquatic biology, sanitary engineering, pathology or disease study and control) and appropriate governmental departments (*eg*, fishery management, public health, wastewater management and control) are most appropriate to achieve this end by producing results which can be accepted by all.

From a purely fish culture standpoint, additional documentation of the lesser potential of zoonoses through fish than through warm-blooded animals would enhance the status of using waste waters for fish culture. Technical support by international or national agencies aiding developing countries to study wastewater utilization in countries with hot climates would be a judicious use of research funds, especially with regard to human pathogens which tend to be more diverse, ubiquitous and virulent in tropical areas. In temperate climates, utilization of waste waters during the winter has been started by utilizing waste heat in aquaculture systems, but is probably restrained by institutional blocks, *ie*, the land, waste water, heat, need for fish protein and expertise may not all be at the same location. Some developing countries, however, may have the option of planning to have all these elements in the same location and to arrange for administrative structures which support rather than hinder rational and purposeful re-use of waste waters.

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Use of Agricultural and Urban Wastes in Fish Culture

G. Schroeder and B. Hepher

Abstract

Addition of organic fertilizers, such as manures and sewage, to fish ponds results in increased natural productivity of ponds. The biological oxygen demand (BOD) for organic fertilizers used in ponds can be estimated through the relatively simple determination of percent dry matter contained in manures. With this ability to predict rate of oxygen depletion, manures can be safely added to ponds at daily rates in excess of 2 tons/ha.

Cow manure and sewage from small towns are quantitatively demonstrated to be commercially useful bases for natural fish foods. Cow manure, applied at daily rates of 250–400 l/ha/day for each ton of fish as the fish biomass increased from less than 500 kg/ha to greater than 4 000 kg/ha, resulted in fish yields of 20–40 kg/ha/day with no use of supplemental feeds. Intensive manuring in conventionally fed fish ponds resulted in doubled yields of fish with half the usual feed requirement.

Sewage from a town of 5 000 fed directly into a 4 ha reservoir pond yielded 2 800 kg fish/ha/6 months with no supplemental feeding. Sewage from a 500 person kibbutz, fed into 3 ha of fish ponds which received supplemental feeds, yielded 8 600 kg fish/ha/8 months as compared to 4 700 kg/ha/8 months in adjacent ponds not receiving sewage. Fish grown in sewage are held for several weeks in freshwater ponds as a safety precaution. This 'flush-out' period is to remove residual objectionable odours and pathogens.

Utilisation de déchets agricoles et urbains en pisciculture

Résumé

L'adjonction d'engrais organiques (fumures, eaux usées) a amélioré la productivité des étangs d'élevage. La demande biologique d'oxygène (DBO) des engrais organiques utilisés dans des étangs peut être estimée d'après la teneur de la fumure organique en matière sèche, qui est assez facile à calculer. Grâce à cette possibilité de prédire le taux de déperdition d'oxygène, on peut appliquer sans danger des doses journalières de plus de 2 tonnes par hectare.

Les chiffres montrent que le fumier de vache et les effluents domestiques des petites villes sont commercialement utilisables comme aliments naturels en pisciculture. Une application de 250–400 l de fumier de vache par jour et par tonne de poisson, la biomasse de poisson passant de moins de 500 kg à plus de 4 000 kg par hectare, a donné des rendements de 20 à 40 kg de poisson par hectare et par jour, sans aliments supplémentaires. Dans des élevages à alimentation traditionnelle la fumure intensive a permis de doubler les rendements en réduisant de moitié les rations.

En six mois, sans distribution d'aliments, on a obtenu 2 800 kg de poisson par hectare dans un étang de 4 hectares qui recevait directement les eaux usées d'une ville de 5 000 habitants. Les effluents domestiques d'un kibboutz de 500 personnes déversés dans un étang de 3 hectares où le poisson recevait des aliments supplémentaires ont donné un rendement de 8 600 kg par hectare en huit mois alors que les etangs voisins qui ne recevaient pas les eaux usees ont eu un rendement de 4 700 kg. Par mesure de précaution, les poissons élevés dans les eaux usées sont logés ensuite, pendant plusieurs semaines, dans des étangs d'eau douce. Ce stage permet d'éliminer totalement les odeurs et pathogènes résiduels.

Empleo de desechos agrícolas y urbanos en la piscicultura

Extracto

La introducción de fertilizantes orgánicos tales como abonos y aguas de alcantarillado en los estanques piscícolas permite aumentar su productividad natural. La demanda biológica de oxígeno (DBO) de fertilizantes orgánicos usados en estanques puede estimarse determinando, con un cálculo relativamente sencillo, el porcentaje de materia seca de los abonos. Gracias a esta posibilidad de prever el índice de consumo de oxígeno se pueden añadir abonos sin peligro a los estanques en proporciones diarias superiores a 2 toneladas/ha.

Se ha demostrado cuantitativamente que las bostas de bovinos y el agua de alcantarillado de pequeñas ciudades constituyen una base comercialmente útil para facilitar piensos naturales a los peces. Las bostas de bovinos, aplicadas en proporción de 250–400 l/día por cada tonelada de pez, según la biomasa íctica aumentó de menos de 500 kg/ha a más de 4 000 kg/ha, permitió obtener rendimientos de 20–40 kg/ha/día sin utilizar piensos suplementarios. El abonar intensivamente los estanques de peces alimentados con los métodos tradicionales permitió obtener rendimientos dobles de peces con la mitad de los piensos utilizados usualmente.

Las aguas de alcantarillado de una ciudad de 5 000 personas, descargadas directamente en un embalse de 4 ha, permitieron obtener 2 800 kg de pescado/ha/6 meses sin alimentación supplementaria. Las aguas de alcantarillado de un kibutz de 500 personas, descargadas en 3 ha de estanques piscícolas los cuales recibieron además piensos suplementarios, permitieron obtener 8 600 kg de pescado/ha/8 meses frente a 4 700 kg/ha/8 meses en estanques adyacentes que no recibían aguas de alcantarillado. Los peces cultivados en agua de alcantarillado se mantienen durante varias semanas en estanques de agua dulce, como una medida de seguridad. Este período de "limpieza" es para remover todos los olores desagradables y los agentes patógenos residuales.

1 Introduction

During the past three years organic wastes have been used extensively in fish ponds in Israel with the objective of replacing part of, or all, supplemental feeding. Experiments were conducted under carefully controlled conditions in 400 m^2 ponds and also under normal operating conditions in commercial fish ponds ranging in size from 0·5 to 10 ha. In the controlled experiments, fluid cow manure containing urine and faeces was used while, in the commercial ponds, fluid manure or sewage from small towns was used. In all cases, the use of organic wastes resulted in large increases in fish yield per unit area of pond as well as sharp decreases in the feed conversion coefficient. Some aspects of this work have been reported previously by Hepher and Schroeder (1974; 1977) and Schroeder (1975; 1975a). This paper summarizes the effects of manure on the aquatic environment and the increased production levels achieved through the addition of different organic wastes to fish ponds.

2 Effects of manures on the aquatic environment

A study of conditions in, and productivity of, 35 commercial fish ponds with fish stocking densities ranging from 1 to 5 tons/ha revealed that the amount of natural food in the ponds was the most important parameter determining the efficiency with which supplemental feed was utilized by the fish for growth (Schroeder, 1973; 1974). This knowledge led to the investigation of inexpensive methods for increasing the productivity of natural fish food organisms in ponds. Fluid cow manure containing urine and faeces, was found to be a successful nutrient for growing natural foods, and standing crops of zooplankton and chironomids were 10 times greater in manured ponds than in non-manured ponds.

This increase in natural foods was brought about through the effects of manure on two basic food chains. The mineralized fraction of the manure provides nutrients for enhancing the growth of phytoplankton which, in turn, produces oxygen through photosynthesis, while the non-mineralized fraction of the manure is used as a food base for bacteria and protozoa. Zooplankton appear to ingest small manure particles, digest the bacteria with which the particles are coated and then expel the residual particles. This was demonstrated in an experiment covering a period of 80 days when dense populations of *Daphnia* were cultured in dark aerated jars receiving fluid cow manure at a daily rate of 1 part manure per 1 000 to 10 000 parts of water. The absence of light eliminated photosynthetic production of plankton as a food source, so manure was the only food available. *Daphnia* grazed actively on the suspended particles, and investigation of the gut contents of *Daphnia* showed that they contained bacteria. Conversely, in dark, aerated but non-manured jars, which initially contained *Daphnia* at the same density as in manured jars, the *Daphnia* population neared extinction after only three days.

Inherent in the intense use of organic wastes in ponds is the hazard of fish kill due to depletion of dissolved oxygen in the water brought about by decay of the added organic matter. During investigation of this problem, it was determined that oxygen depletion resulting from addition of manure could be quantitatively predicted from measurements of the biological oxygen demand (BOD) of the manure at pond temperature (Schroeder, 1974a). The BOD, in turn, could be estimated from the percent dry matter contained in the manure. Since dry matter content is more easily and rapidly measured than BOD, this is often a convenient method for estimating BOD. With the ability to predict oxygen depletion, it was feasible to add manure safely at daily rates in excess of 2 tons/ha.

In a properly manured fish pond, the dissolved oxygen concentration is usually higher after the initial week of fertilization than in comparable non-manured fish ponds because of the increased phytoplankton populations producing oxygen through photosynthesis.

3 Manuring and its effect on fish production

3.1 *Domestic animal manures*

The general procedure for applying manure to large commercial fish ponds was determined in experimental 400 m^2 ponds (0·7 m deep) at the Dor Fish and Aquaculture Research Station, Israel (Wolfarth *et al*, 1975). Ponds were stocked with common carp, (*Cyprinus carpio*), silver carp (*Hypophthalmichthys molitrix*), and tilapia (*Tilapia aurea*) in a ratio of approximately 3:1:2.

For a fish biomass of less than 2 ton/ha, manure containing 12% dry matter was applied 6 days per week at a daily rate of 250 l manure/ton fish. Ammonium sulphate (21% N) and superphosphate were applied every two weeks at 600 kg/ha. When chicken manure was available, 200 l/ha was applied once in two weeks. When the fish biomass exceeded 2 ton/ha the rate of manuring was raised to 400 l/ton fish. The rate of chemical fertilization remained constant at all times. Fish yields throughout the spring, summer and autumn (water temperatures of 20–26°C, 25–32°C and 20–26°C respectively) ranged from 20 to 40 kg/ha/day without supplemental feeding. Observations of the relative growth rates of the three fish species in manured ponds indicate that, of the three species, tilapia and silver carp are most readily grown in manured ponds when no supplemental feeds are supplied. Common carp benefits from the addition of grain or feed pellets at a rate of about 2% of the common carp biomass.

Analysis of protein (calculated as 6·25 times organic nitrogen determined by the Kjeldahl method) in plankton populations present in the ponds consistently showed 45% and 55% protein content (dry weight) for phytoplankton and zooplankton respectively. This natural food provided the fish with a diet twice as rich in protein as the normal 25% protein in content of pelletized feeds conventionally used in Israel fish culture. Wolfarth *et al* (1975) found that carp grown in intensively manured non-fed ponds had a 4% fat content, as compared with a greater than 10% fat content for carp receiving conventional feeds.

An 80 day intense manuring trial in a 0·5 ha pond (1–2 m deep) gave an average fish yield of 30 kg/ha/day. A 2 ha pond (1–2 m deep) receiving intense manuring and supplemental feed yielded 7 500 kg/ha/8 months or about 30 kg/ha/day at a feed conversion coefficient of 1:1. Adjacent non-manured ponds provided approximately 60% of this yield with a feed conversion coefficient of about 1:1·8. In a 10 ha reservoir pond (6 m deep), which was intensively manured for half the growing season, and supplied with pelleted feed daily during the entire season at a rate of about 3% of the fish biomass, there was a feed conversion coefficient of 1:1·2 as compared with a usual coefficient for non-manured ponds of 1:2·6. In the manured pond the

fish also reached market size more than 1 month sooner than in non-manured ponds. In these examples manure was poured into the ponds at one location. The results from the 2 and 10 ha ponds indicate that natural pond circulation is adequate to spread the added nutrients throughout large ponds.

3.2 *Human sewage*

Human sewage is equally efficient as other animal manures in increasing fish growth in ponds but aesthetic considerations often limit its use. However, holding the fish in clean water ponds for several weeks at the end of the growing season has proved to be a pragmatic method for providing fish acceptable for market. This flush-out period is to remove residual objectionable odours and pathogens.

As an example of use of human wastes as a fertilizer for fish, sewage from a town of 5 000 people, fed directly into a 4 ha reservoir fish pond, yielded 2 800 kg/ha/6 months. The low growth rate of silver carp observed in this pond (less than 4 g/day average versus 10 g/day for the same pond during a 6 month season when an ammonia-based fertilizer was used) implied that adding a nitrogen-rich fertilizer would raise the yield in this pond to 3 800 kg/ha/6 months.

Sewage from a kibbutz of 500 people fed into fish ponds having an area of 3 ha and receiving supplemental feeds at daily rates of 3–4% of the fish biomass but without chemical fertilization, yielded 8 600 kg/ha/8 months with a feed conversion coefficient of 1:1. Adjacent non-sewage ponds receiving chemical fertilization and similar supplemental feeding yielded 4 700 kg/ha/8 months with feed conversion coefficients of 1:2.

It has been observed that sewage treatment ponds stocked with fish have higher average dissolved oxygen concentrations and pH than similar ponds without fish (Schroeder, 1975). Fish graze on plankton, reducing their density and eliminating cycles of plankton bloom and die-off which are typical in ponds receiving organic wastes. Hence, the effectiveness of sewage ponds is actually improved by stocking fish.

The entire fish-culture/sewage-treatment system can therefore be considered to be a symbiotic relationship with the fish improving the treatment of sewage waste, and the sewage increasing the yield of fish.

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Experiments in Recycling Swine Manure in Fishponds

D. H. Buck, R. J. Baur and C. R. Rose

Abstract

This is believed to have been the first attempt in North America to utilize certain Asian cultures and techniques in the solution of such problems as animal waste management, pollution control, and the production of protein. Two small Illinois ponds of similar size received nearly identical stockings of fish (three Chinese carps, common carp, largemouth bass, a hybrid buffalo fish and channel catfish), but differing amounts of swine manure. One pond (0·127 ha) received the total wastes from five growing pigs (about 39 pigs/ha of water area), the other pond (0·121 ha) received the wastes from eight pigs (66 pigs/ha). Two consecutive lots of pigs were fattened during the experiment. Water levels were lowered at mid-season to improve natural circulation, but conditions were otherwise static, with no artificial circulation or aeration. Over a fish-growing period of about 170 days (May to October 1975) the net increments in fish biomass were at the rates of 2 971 kg/ha in the 0·127 ha pond, and 3 834 kg/ha in the 0·121 ha pond. The high production of fish was attributed to: (*i*) the high quality of the swine rations; (*ii*) an efficient density of stocking ratio of fish species; and (*iii*) effective water level management. A beneficial influence by the fish population on water quality was indicated by continuously adequate levels of dissolved oxygen, and final BODs in the range of 8–12 mg/l.

Essais de recyclage du fumier de porc dans des étangs piscicoles

Résumé

C'est apparemment la première fois que l'on a essayé en Amérique du Nord de recourir à certaines cultures et techniques asiatiques pour résoudre des problèmes tels que l'élimination des déchets animaux, la lutte contre la pollution et la production de protéines. Deux petits étangs de l'Illinois de dimensions semblables ont reçu à peu près la même charge de poissons (trois carpes chinoises, carpe commune, perche-soleil, un hybride de cyprin-carpe et poisson-chat), mais différentes quantités de fumier de porc. On a déversé dans un étang (0,127 ha) l'ensemble des déchets de cinq porcs en cours de croissance (soit environ 39 porcs/ha de superficie aquatique), et dans l'autre (0,121 ha) les déchets de huit porcs (66 porcs/ha). Deux lots consécutifs de porcs ont été engraissés au cours de l'expérience. Le niveau de l'eau a été abaissé à mi-chemin de l'experience pour améliorer la circulation naturelle mais, cela mis à part, les conditions sont demeurées inchangées, sans circulation artificielle ni aeration Pendant une periode de croissance des poissons d'environ 170 jours (mai–octobre 1975), l'augmentation nette de la biomasse ichtyologique a été de 2 971 kg/ha dans l'étang de 0,127 ha et de 3 834 kg/ha dans celui de 0,121 ha. La production élevée de poisson a été attribuée: (*i*) à la haute qualite des aliments donnés aux porcs, (*ii*) au taux de charge optimal des étangs en poissons; et (*iii*) à la régulation efficace du niveau de l'eau. Les poissons ont exercé une influence bénéfique sur la qualité de l'eau à en juger d'après les teneurs continuellement adéquate en oxygène dissous et les DBO finales comprises entre 8 et 12 mg/l.

Experimentos de reciclaje de estiercol de cerdo en estanques piscícolas

Extracto

Se cree que este es el primer experimento hecho en América del Norte sobre la utilización de determinados cultivos y técnicas asiáticos para resolver algunos problemas de eliminación de desechos de animales, control de la contaminación y producción de proteínas. En dos pequeños estanques de Illinois de dimensiones análogas se sembró la misma cantidad de peces (tres carpas chinas, carpa común, lobina de boca grande, un híbrido de catostómido y bagre de canal), vertiendo en ambos cantidades distintas de estiércol de cerdo. En un estanque (0,127 ha) se vertieron todos los desechos de cinco cerdos (unos 39 cerdos/ha de superficie de agua), y en el otro (0,121 ha) los de ocho cerdos (66 cerdos/ha). Durante el experimento se engordaron dos lotes consecutivos de cerdos. A mediados de la temporada se redujo el nivel del agua para mejorar la circulación natural, pero, por lo demás, las condiciones se mantuvieron estáticas, sin circulación ni aireación artificiales. Durante un periodo de crecimiento de los peces de unos 170 días (de mayo a octubre de 1975), el incremento neto de la biomasa íctica fue del orden de 2 971 kg/ha en el estanque de 0,127 ha y de 3 834 kg/ha en el estanque de 0,121 ha. La elevada producción íctica se atribuyó a: (*i*) la alta calidad de las raciones de los cerdos; (*ii*) la densidad de siembra de las diversas especies; y (*iii*) la buena administración del nivel del agua. La influencia beneficiosa de la población íctica en la calidad del agua quedó demostrada por el hecho de que el nivel de oxígeno disuelto fue

siempre suficiente y la demanda biológica de oxigeno se mantuvo en limites de 8 a 12 mg/l.

1 Introduction

This study was an initial attempt to adapt certain Asian cultures and techniques to North American agricultural systems. The studies were conducted at the Sam A. Parr Fisheries Research Center, near Kinmundy, Illinois. Preliminary information was obtained from studies made in 1974 using 3 m diameter pools, but the present report will treat only the results obtained in 1975 using two small earthen ponds.

2 Procedures

2.1 *Description of ponds*

Two ponds, rectangular in shape, were oriented to provide maximum circulation by moderate winds which prevailed from the south. The ponds had been constructed in 1966 in relatively infertile clay. Previous pond treatments had been similar. The ponds were filled simultaneously from a supply reservoir over the period 29 April–16 May 1975 providing initial areas of 0·141 ha for pond 11 and 0·138 ha for pond 12 with maximum depths of about 2 m and average depths of about 1 m in each. On 25 July 1975, the water levels were lowered about 0·67 m in each pond in order to improve natural circulation and to remove the bottom strata in which oxygen levels had declined to about 1 mg/l. During the remaining 95 days of the fish-growing period, pond 11 maintained an area of about 0·121 ha and a maximum depth of about 1·4 m; for pond 12, the area was 0·113 ha with a maximum depth of about 1·2 m. At all other times the pond waters remained static with no artificial circulation or aeration and with no addition of water except from direct rainfall and from several trickles from a perforated pipe located above floors of a swine house (see section 2.3). These trickles served as a water supply for the swine and to help wash their manure into the ponds. The total influx of water was small and the water levels fluctuated no more than 2 or 3 cm curing the last 95 days of the experiment.

2.2 *Stocking of fish*

The choice of a stocking ratio was based primarily upon a review of available literature including papers by Hickling (1962), Hora and Pillay (1962), Ling (1966), Rabanal (1966), Yashouv (1966), Tang (1970), Singh *et al* (1972), Lin (1974), and numerous reports in the FAO Aquaculture Bulletin.

Three species of Chinese carps were stocked: silver carp (*Hypophthalmichthys molitrix*), bighead carp (*Aristichthys nobilis*), and grass carp (*Ctenopharyngodon idella*). The other species stocked were: the Israeli variety of the common carp (*Cyprinus carpio*), the northern largemouth bass (*Micropterus salmoides salmoides*), the channel catfish (*Ictalurus lacustris*), and a hybrid buffalo derived from a cross of a bigmouth buffalo female (*Ictiobus cyprinella*) and a black buffalo male (*I. niger*). Nearly identical stockings were made in each pond (Table I). Initial mortality was highest among the smaller sizes of silver carp. Total mortality was highest for the buffalo, exceeding 95% in both ponds (Table II), due primarily to heavy infestations by an anchor parasite (*Lernea* sp.).

TABLE I

DATES OF FISH STOCKING, INITIAL AVERAGE INDIVIDUAL WEIGHTS, NUMBERS STOCKED, AND STOCKING RATES IN NUMBERS/HA FOR SEVEN SPECIES OF FISH STOCKED IN EACH OF TWO EXPERIMENTAL PONDS

Fish species	*Date stocked* (1975)	*Average weight* (*g*)	*Actual number*	*Number/ha*[a]
Silver carp	9/5	9	500	4 260
Silver carp	23/5	150	80	682
Israeli carp	12/5	82	200	1 704
Bighead carp	9/5	45	50	426
Grass carp	9/5	64	15	128
Hybrid buffalo[b]	9/5	9	350	2 892
Channel catfish	9/5	27	20	128
Largemouth bass	26/5	18	15	121

[a] Approximate, due to slight differences in sizes of ponds
[b] Bigmouth buffalo female x black buffalo male

TABLE II

INITIAL AND FINAL BIOMASSES, NUMBER OF GROWING DAYS, PERCENT MORTALITIES, NET GAINS IN BIOMASS, AND PERCENTS OF TOTAL GAIN MADE BY EACH SPECIES OF FISH IN PONDS 11 (39 PIGS/HA) AND 12 (66 PIGS/HA)

Fish species	*Initial biomass* (*kg/ha*)		*Final biomass* (*kg/ha*)		*Growing days*	*Percent mortality*		*Gain in biomass* (*kg/ha*)		*Percent of total gain*	
	P 11	*P 12*	*P 11*	*P 12*		*P 11*	*P 12*	*P 11*	*P 12*	*P 11*	*P 12*
Silver carp	102	107	1 912	2 590	170[b]	18	8	1 810	2 483	61·00	65·00
Israeli carp	131	139	741	928	170	13	11	610	789	21·00	21·00
Bighead carp	17	15	456	444	173	6	2	439	429	15·00	11·00
Grass carp	8	8	79	97	173	69	44	71	89	2·00	2·00
Hybrid buffalo[a]	30	31	49	40	173	97	96	19	9	0·60	0·20
Channel catfish	4	4	24	36	173	5	0	20	32	0·70	0·80
Largemouth bass	2	2	4	5	156	40	53	2	3	0·06	0·08
Total	294	306	3 265	4 140	—	42	36	2 971	3 834	100·36	100·08

[a] Bigmouth buffalo female x black buffalo male
[b] Approximate average for two groups stocked on different days

2.3 *Swine management and introduction of manure*

A two-section swine house was constructed near the mid-point of a dike which separated the two ponds. Five growing pigs were maintained on a cement floor which sloped toward pond 11, providing a density of about 39 pigs/ha of pond water area. Eight pigs were maintained over the floor which sloped toward pond 12, providing a density of about 66 pigs/ha of pond water area. Two lots of pigs were fattened during the course of the experiment. The first lot was placed in the swine house on 29 April 1975, 10 days before the introduction of fish. These pigs had an average weight of about 32 kg when introduced, and about 88 kg when replaced by others on 3 July. The pigs which replaced them had an initial average weight of about 43 kg and a final weight of about 100 kg when removed on 1 October 1975. The pigs were fed standard rations used in swine production by the University of Illinois. Pigs lighter than 54 kg were fed a ration containing 16% protein; for heavier animals the protein content of the feed was reduced to 12%. Ingredients of the rations are shown in Table III.

TABLE III
INGREDIENTS OF THE SWINE RATION IN KG

Ingredients	*16% ration*	*12% ration*
Ground yellow corn	791·5	888·5
Soybean meal	180·0	90·0
Dicalcium phosphate	10·0	10·0
Ground limestone	10·0	7·0
Trace mineralized salt	5·0	3·5
Illini vitamin mix	1·0	0·5
Aureo-SR-250	2·5	—
Pro strep	—	0·5
Total	1 000·0	1 000·0

3 Results

3.1 *Fish production*

The ponds were drained and the fish populations censused on 28 and 29 October 1975. The production data presented in Table II were computed on the basis of estimated seasonal averages of the area of each pond: 0·127 ha for pond 11, and 0·121 for pond 12. The production figures would have been larger if based on the pond dimensions which prevailed over the last 95 days, which represented about 56% of the growing period. For pond 11 (final area: 0·121 ha), the net gain in biomass would have been 3 128 kg/ha; for pond 12 (final area: 0·113 ha), the gain would have been 4 107 kg/ha.

Table IV shows that the largest gains by individual fish were made by the grass carp, followed by the bighead carp, but that the largest total gain by a species was made by the more numerous silver carp. Individual gains made by the buffalo closely approximated those made by the Israeli carp, but their total contribution was small due to high mortality. Gains made by the largemouth bass and channel catfish ranked far below those made by the hybrid buffalo and the carps, and below levels which these native species commonly achieved.

3.2 *Water quality characteristics*

Lin (1974) has proposed the use of Chinese carps to control eutrophication and to purify waters polluted by domestic sewage. It is believed that the Chinese carps achieved these functions in the present experiments, as indicated by the levels of dissolved oxygen, ammonia, BOD, and other water-quality criteria listed in Table V.

4 Discussion

The production of fish in both experimental ponds was high. The final biomass in pond 11 was 3 265 kg/ha, the gain in biomass 2 971 kg/ha. In pond 12, the final biomass was 4 140 kg/ha, the gain in biomass 3 834 kg/ha.

Such high rates of fish production in waters which

TABLE IV
INITIAL AND FINAL AVERAGE WEIGHTS, NUMBER OF GROWING DAYS, AND WEIGHT GAINS FOR FISHES IN PONDS 11 (39 PIGS/HA) AND 12 (66 PIGS/HA)

Fish species	*Initial weight (g)*	*Final weight (g)*		*Growing days*	*Daily gain/fish (g)*		*Daily gain/ha (kg)*	
		P 11	*P 12*		*P 11*	*P 12*	*P 11*	*P 12*
Silver carp	9 and 150[a]	621	712	159–173	3·43	3·97	10·59	14·41
Israeli carp	82	544	635	170	2·72	3·25	3·59	4·64
Bighead carp	45	1 238	1 170	173	6·90	6·50	2·54	2·48
Grass carp	64	2 000	1 306	173	11·19	7·18	0·41	0·51
Hybrid buffalo	9	522	345	173	2·97	1·94	0·11	0·05
Channel catfish	27	168	222	173	0·82	1·13	0·12	0·19
Largemouth bass	18	59	82	156	0·26	0·41	0·01	0·02

[a] Each pond was stocked on 9 May with 500 silver carp having an average weight of 9 g, and on 23 May with 80 having an average weight of 150 g. Gains computed for silver carp were prorated because size classes were not distinguishable in the final censuses

TABLE V
RANGES AND MEANS OF VARIOUS PHYSICAL AND CHEMICAL PARAMETERS OF THE POND WATERS

	Pond 11		*Pond 12*	
	Range	*Mean*	*Range*	*Mean*
Surface temperature, °C[a]	16·8 –29·0	24·7	16·8 –28·8	24·4
DO at 0·91 m, mg/l	3·4 – 6·7	5·3	1·3 – 7·8	3·9
DO at bottom, mg/l[b]	1·7 – 6·6	4·1	0·8 – 7·4	2·2
pH	7·6 – 8·8	7·8	7·3 – 8·4	7·8
M. O. alkalinity	64·0 –82·0	75·3	59·0 –92·0	80·5
Ammonia, mg/l NH_3–N	0·16– 0·78	0·43	0·22– 1·24	0·52
BOD[c]	3·9 –11·0	8·2	8·7 –27·1	16·1

[a] Temperatures were below 20°C for only a brief period in September
[b] Lowest DO recorded was 0·8 mg/l at bottom of pond 11 at midnight on 18 June
[c] BOD decline from mid-August maxima of 11·0 mg/l in pond 11, and 27·1 mg/l in pond 12, to final levels of 8·6 in pond 11, and 11·7 in pond 12

received only moderate rates of enrichment by Asiatic standards and which received no supplementary feeding were a source of surprise to the writers. Contributing factors are believed to have included: (*i*) the high quality of the feed provided to the swine; (*ii*) an efficient density and stocking ratio of fish species; and (*iii*) effective water-level management.

Future efforts will determine whether a fortuitous combination of factors provided a rate of production which could not be consistently achieved or if this initial high rate of production can be surpassed.

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Preliminary Bacteriological Studies on Wastewater-Fertilized Marine Fish Ponds, Humboldt Bay, California

G. H. Allen, R. A. Busch and A. W. Morton

Abstract

Aquaculture systems utilizing waste waters have potential micro-biological problems associated with: (*i*) the health of the fish that are cultivated, (*ii*) the transmission of human pathogens; and (*iii*) maintenance of the quality of aquaculture effluents discharged to receiving waters.

Results, with respect to these problems, are given from studies undertaken during 1971–75, of microbiological properties found in two domestic wastewater-fertilized marine fish ponds at Arcata, Humboldt Bay, California, used to rear juvenile Pacific salmon (*Oncorhynchus* spp.) and rainbow trout (*Salmo gairdneri*).

Bacterial groups *Aeromonas*, *Pseudomonas*, Escherichieae, Salmonelleae, *Streptococcus*, and Klebsielleae were isolated from gastrointestinal tract washings, but no bacterial pathogens were isolated from other visceral organs studied. There was no evidence that any of the potential pathogens had become systemic under the fish culture conditions in use. The time between release of juvenile salmon and their capture as adult salmon in commercial and recreational fisheries would provide adequate time for depuration.

Total coliform MPN index and faecal streptococci levels were always high in unchlorinated oxidation pond waters and also in an urban stream (Jolly Giant Greek) which empties into Humboldt Bay adjacent to the fish ponds. Levels of these parameters were always much lower in fish pond waters, especially waters allowed adequate retention time prior to discharge. Circumstantial evidence indicated high levels of *Chlorella*—inhibited faecal streptococci.

Vibrio anguillarum was isolated in juvenile salmon being reared in the ponds, but the overall mortality rates of wastewater-reared salmonids from this disease were lower than those reported for other salmon-rearing areas. Circumstantial evidence continues to support a concept of a beneficial effect on the health of salmonids reared in mixtures of oxidation pond effluent and sea water used in the Arcata aquaculture ponds.

Etudes bactériologiques préliminaires dans des étangs de pisciculture marine fertilisés par des eaux résiduaires (Baie de Humboldt, Californie)

Résumé

Les systèmes d'aquaculture qui utilisent des eaux résiduaires peuvent se heurter à des problèmes microbiologiques associés aux facteurs suivants: (*i*) la santé du poisson que l'on y élève; (ii) la transmission d'organismes pathogènes de l'homme; et (*iii*) le maintien de la qualité des effluents aquicoles déversés dans les eaux réceptrices.

Les résultats relatifs à ces problèmes sont fournis d'études entreprises en 1971–75 concernant les propriétés microbiologiques observées dans deux étangs de pisciculture marine fertilisés par des eaux résiduaires, situés à Arcata, Baie de Humboldt, Californie et utilisés pour l'élevage de jeunes saumons du Pacifique (*Oncorhynchus* spp.) et de truites arc-en-ciel (*Salmo gairdneri*).

Les groupes bactériens d'*Aeromonas*, de *Pseudomonas*, d'Escherichieae, de Salmonelleae, de *Streptococcus*, et de Klebsielleae ont été isolés de lavages gastrointestinaux. Cependant aucun agent pathogène bactérien n'a été isolé des autres organes viscéraux étudiés. Aucune évidence n'a été établie que quelconque des germes pathogènes potentiels n'était devenu systemique dans les conditions de pisciculture utilisées. La période s'écoulant entre le lâchage en mer des jeunes saumons et leur capture à l'état adulte dans les pêcheries commerciales et sportives devrait suffire pour la dépuration.

L'index coliforme total (MPN) et les niveaux de streptocoques fécaux ont toujours été élevés dans les eaux des étangs d'oxydation non chlorinés ainsi que dans la rivière urbaine (Jolly Giant Creek) se jetant dans la Baie de Humboldt près des étangs de pisciculture. Les niveaux de ces parametres ont toujours été bien plus bas dans les eaux de ces étangs, surtout dans celles ayant été retenues un temps adequat avant d'être déchargées. L'évidence circonstancielle a indique que de hauts niveaux de population de *Chlorella* avaient un effet inhibitant sur les streptocoques fécaux.

Vibrio anguillarum a été isolé dans les jeunes saumons élevés dans les étangs, mais les taux de mortalité dûs à cette maladie chez les salmonides cultivés dans les eaux résiduaires ont été moins élevés que ceux observés dans d'autres régions d'élevage du saumon. L'évidence circonstancielle continue à supporter le concept d'un effet bénéfique sur la santé des salmonides cultivés dans des mélanges d'effluents d'étang d'oxydation et d'eau de mer, dans les étangs de pisciculture d'Arcata.

Estudios bacteriológicos preliminares en estanques piscícolas de agua de mar fertilizados con aguas residuales (Bahia de Humboldt, California)

Extracto

El empleo en acuicultura de sistemas que utilizan aguas residuales plantea potencialmente problemas microbiológicos relativos a: (*i*) la salud de los peces que se cultivan; (*ii*) la transmisión de agentes patógenos para el hombre; y (*iii*) el mantenimiento de la calidad de las aguas que salen de la explotación acuícola.

Se dan los resultados con respecto a estos problemas, basándose en los estudios realizados durante 1971–75, sobre las propiedades microbiológicas encontradas en dos tipos de estanques piscícolas de agua de mar, los cuales fueron fertilizados con aguas residuales y usados para la cría de juveniles del salmón del Pacífico (*Oncorhynchus* spp.) y la trucha arco-iris (*Salmo gairdneri*) en Arcata, Bahía de Humboldt, California.

Los grupos bacterianos *Aeromonas*, *Pseudomonas*, Escherichieae, Salmonellae, *Streptococcus* y Klebsielleae fueron aislados de lavados procedentes de la vía gastro-intestinal, pero ningún patógeno bacteriano fue aislado de los otros órganos viscerales estudiados. No se encontró evidencia de que cualquiera de los patógenos potenciales se hubiese tornado sistémico bajo las condiciones piscícolas en uso. El tiempo transcurrido entre cuando se liberan los juveniles de salmón y su captura como salmones adultos, en las pesquerías comerciales y de recreación debería dar tiempo suficient para su depuración.

El índice MPN usado en el contaje total de coliformes y los niveles de

estreptococos fecales siempre fueron altos en aguas sin clorinar de estanques de oxidación y en un arroyo urbano (Jolly Giant Creek) que desemboca en la Bahia de Humboldt y que queda adyacente a los estanques piscícolas.

Vibrio anguillarum fue aislado de salmones juveniles que estaban siendo criados en estanques, pero las tasas totales de mortalidad de los salmones criados en aguas residuales a causa de esta enfermedad fueron menores de las informadas de otras áreas dedicadas a la cría de salmones. Evidencia circunstancial continua apoyando el concepto de que el efecto beneficioso sobre la salud de los salmones criados en aguas mezcladas con efluentes de estanques de oxidación y agua de mar usadas en los estanques de acuicultura de Arcata.

1 Introduction

Allen and Hepher (1979) list potential constraints to wider application of domestic waste waters to aquaculture including those involving microbiological properties, especially where the cultured products may be used directly by human beings. These constraints include: (*i*) possible transmission of human pathogens through fish, (*ii*) the need to protect receiving waters from possible negative impacts from aquaculture effluents, and (*iii*) presumably poor fish health resulting from waste water use.

This paper gives the results of studies undertaken on these subjects during 1971–75 in a waste water aquaculture system located at Arcata, on the northern California coast. In 1973, the development of fish pathology facilities within the Fisheries Department at Humboldt State University allowed expanded studies on the bacterial content of these ponds and adjacent waters, along with preliminary studies on fish diseases and zoonoses.

Because data were accumulated under a number of separate studies undertaken at different times, the results are presented separately in the following sequence: (*i*) the pathobiology of cultured fish (an area posing the most serious constraint to use of domestic waste waters in aquaculture); (*ii*) bacterial levels in the Arcata ponds (a local constraint as pond effluent discharges into a receiving water used by a major oyster culture operation); and (*iii*) studies on fish diseases, specifically *Vibrio anguillarum* (a very serious marine bacterial disease of fish).

Salmonids reared in the ponds involved in studies reported here include: chinook salmon (*Oncorhynchus tschawytscha*), coho salmon (*O. kisutch*), kokanee-lacustrine sockeye salmon (*O. nerka*), and rainbow (steelhead) trout (*Salmo gairdneri*).

2 Pond description and operation

The Arcata fish ponds were built as a pilot project (Allen, Conversano and Colwell, 1972) to study the potential for use of salt water fertilized with treated domestic waste waters to rear juvenile salmonids to smolt stage (fish adapted to enter salt water) without supplemental feeding of high-cost protein pellets (Allen and Dennis, 1974). The system consists of two 0·37 ac (0.15 ha) ponds located inside the perimeter of a 55 ac (22 ha) oxidation pond situated on intertidal mud flats. Water entering the Arcata treatment system at a flow rate of 1 mgd (3 770 m^3/day) receives primary settling, clarification, and aeration before entering the oxidation pond. The waste waters receive a high degree of dilution in winter from high rainfall due to considerable infiltration in the sewage collection lines.

The fish ponds can be operated over a wide range of salinities by taking Humboldt Bay water into the ponds and mixing it with waste water drawn from the oxidation pond. The ponds are operated as a static system once the desired sea water-waste water mixture has been obtained for a particular rearing experiment (Allen and Dennis, 1974; Allen and Carpenter, 1975). Until the ponds are drained for recovery of fish, only small amounts of water are added or released to maintain salinities or keep the ponds from flooding. Most experiments to date have been conducted at about 10–15 ppt salinity (a 2–1:1 mixture of sea water and waste water). Almost all experiments have run for at least a month before water was released into Humboldt Bay. No disinfection of pond effluent is provided.

3 Pathobiology

3.1 *Introduction*

Aquatic animals intensively cultured in the presence of enteric micro-organisms run the obvious risk of contamination of significance to public health. In this regard, fish are considered to be indicators of the sanitary condition of the aquatic environment. Their microbial flora directly reflects the microbiological condition of the water from which they are taken (Guelin, 1962). Janssen (1970) indicates the importance of fish as vectors of human infectious diseases. Human bacterial pathogens (*Aeromonas, Mycobacterium, Nocardia, Pseudomonas,* and *Vibrio*), and enteric pathogens, such as *Escherichia, Salmonella* and *Shigella,* have been shown to be carried in and on fish (Sinderman, 1970; Janssen, 1970; Reichenbach-Klincke, 1973). The majority of these infections are carried in the gastro-intestinal tract, and are of primary significance as occupational diseases of fish handlers when fish are improperly processed and when fish products are consumed in the raw state. To investigate the nature and extent of contamination of fish cultured in ponds using treated waste waters, rainbow trout, coho salmon and chinook salmon (Table 1) from Arcata ponds

TABLE I

SPECIES, NUMBER AND REARING AREA OF FINGERLING SALMONIDS IN PONDS FERTILIZED WITH CITY OF ARCATA OXIDATION POND EFFLUENT EXAMINED FOR SELECTED GROUPS OF BACTERIA

Date sampled	*Common name*	*Location*		*HSU experiment number*
		South pond	*North Pond*	
1975				
18 January	Coho salmon[1]	5	6	IX
	Rainbow trout[1]	5	4	IX
18 February	Chinook salmon[2/3]	5	5	X
5 March	Chinook salmon	5	5	X
20 March	Chinook salmon	5	3	X
30 April	Chinook salmon	5	–	X

[1] Fish taken at end of Experiment IX after 82 days rearing (Allen and Dennis, 1974)
[2] Fry introduced into ponds on 4 February 1975
[3] Chinook salmon suffered extensive mortalities in Experiment X from early mid-March (see Fig. 8, Allen and Carpenter, 1975)

were examined for the presence of selected bacteria in the gastro-intestinal tract and other visceral organs.

3.2 *Materials and methods*

Five fish from each cultured lot (experiment) were examined for the presence of selected bacteria (Table 1). The liver, kidney, spleen and gastro-intestinal tract washings were aseptically removed as described by Bullock (1971). Five fish samples were pooled by tissue in 5·0 ml of 0·5% sterile tryptone and macerated with a Ten Broeck tissue grinder. Prepared pools were plated on Eosin Methylene Blue agar (Difco), Pseudocel agar (BBL), Tryptic Soy agar (Difco), Tryptic Soy agar with 5·0% whole human blood and vibrio isolation agar (Vanderzant and Nickelson, 1972). All media were incubated at room temperature (20°–22°C) for 48–72 hours. Representative colonies were subcultured on stock slants for further morphological and biochemical identification. Isolates were classified according to the schemata of Bailey and Scott (1974), Lennette, Spaulding and Truant (1974) and Buchanan and Gibbons (1974). Epizootic mortalities and moribund fish were examined pathologically to determine the etiological agent.

3.3 *Results*

A variety of enteric and other bacteria were routinely isolated from the pooled gastro-intestinal tract washings. Representative isolates were identified as shown in Table II. Examination of the other visceral organs failed to yield any bacterial isolations indicating a lack of systemic involvement. Mortalities occurring during this period were routinely attributed to physiological stress associated with abrupt changes in pH and salinity. *Vibrio anguillarum* was determined, however, to be the causative agent of an epizootic occurring during warmwater periods and crowded conditions in recirculating aquaria but not in pond waters (see section 5).

3.4 *Discussion*

Enteric bacteria are not considered normal flora of fish gastro-intestinal tracts and their presence indicates contamination of the waters from which they were taken (Guelin, 1962). Table II shows that 45% of those microorganisms recovered from washings of the gastro-intestinal tract were Enterobacteriaecae. These results indicate a contamination of public health importance of both fish and water. If such fish were to be reared to commercial size and immediately processed for human consumption, there would be a potential for contamination of the product with bacteria of public health significance. This supports the practice followed in German and Israeli commercial waste water fish-culture systems of placing fish into clean water to purge them prior to processing. In the Arcata system, release of juvenile fish into the open ocean for recovery as feeding adults at a minimum of a year later provides adequate time for depuration.

A demonstrated potential does exist for the adaptation of obligate human pathogens to become pathogenic for fish and thereby develop endemic reservoirs for future human infection (Bullock, 1971). The results obtained from the kidney, liver and spleen samples indicate that none of the potential pathogens became systemic under the fish culture conditions used here.

TABLE II

PERCENT RECOVERY OF SELECTED GROUPS OF BACTERIA FROM THE GASTRO-INTESTINAL TRACT WASHINGS OF CHINOOK AND COHO SALMON AND RAINBOW TROUT REARED IN PONDS FERTILIZED WITH CITY OF ARCATA OXIDATION POND EFFLUENT

Bacterial groups	*Percentage recovery*
Aeromonas	22
Pseudomonas	22
Escherichieae	22
Salmonelleae	15
Streptococcus	11
Klebsielleae	8
	100

4 Bacterial levels in pond waters

4.1 *Introduction*

The major public health concern in north Humboldt Bay from domestic waste water discharge into the bay is contamination of commercially grown oysters, although harvesting of bivalves in general is also involved. The oyster-farming industry is located on state lands located about two miles (3·2 km) from the Arcata waste water aquaculture system. Bivalve harvesting here may be curtailed when overlying waters are believed to be overloaded with human pathogens (Calif. State Dept. Public Health, 1973 and 1973a; Beilfuss, 1967). Under a local authority (North Coastal Region Water Quality Control Board), a programme has been in effect for the Arcata aquaculture system to ensure at least minimal protection of values associated with receiving waters, especially the oyster industry. First, at least a two week retention of oxidation pond effluent in fish ponds is required before release to the Bay; secondly, the total coliform MPN index must be determined prior to pond drainage, and reported. In practice, most waters have been retained at least a month before any discharges are made. As the ponds are not operated on a continuous flow-through regime, most waste waters are only discharged when the ponds are drained at the end of a rearing experiment.

Reported here are values of a commonly required bacterial standard (total coliform MPN index) and some values for another indicator, faecal streptococci, found in Arcata waste water aquaculture ponds and adjacent waters.

4.2 *Methods*

The total coliform index (MPN/100 ml) as determined by procedures outlined in Taras (1971) has been routinely determined. Additional data on total bacteria, faecal coliforms, and faecal streptococci have been gathered. Only data on total coliforms and faecal streptococci will be reported here. Faecal streptococci counts beginning in May 1975 have been run by the membrane filtration technique on M-enterococcus agar with prior enrichment in M-PYC media (Taras, 1971). Only a few values for total coliforms using the newer membrane filter (MF) techniques have been determined for comparison with MPN values, and these MF values have fallen within the 95% confidence intervals for the corresponding MPN index. Comparative MPN and MF values are both listed where available.

4.3 *Results*

4.3.1 *Total coliforms.* Initial studies on coliforms were undertaken in August 1971 immediately after the first use of oxidation pond effluent and salt water to obtain water of

19 ppt salinity (Allen, 1973). Total coliform index was greater than $1{\cdot}1 \times 10^3$ (MPN/100 ml) in the first pond to be operated (North Pond). These values dropped to $1{\cdot}1 - 9{\cdot}3 \times 10^1$ in eight days (Allen, 1973). The second pond (South Pond), which did not receive waste water, had a much lower initial value ($4{\cdot}6 \times 10^2$) and dropped to $9{\cdot}3 \times 10^1$ in two days. These initial high counts in South Pond could be attributed to residual populations of bacteria in muds deposited during operation of the oxidation pond. A much more intensive and controlled study of coliform levels and die-off rates was completed in the autumn of 1972 (Donnelly and Inouye, 1974). Two days after a 50% mixture of oxidation pond effluent and sea water was placed into North Pond, coliform levels of about $2{\cdot}25 \times 10^3$ were recorded, which dropped steadily to less than $2{\cdot}5 \times 10^2$ in 14 days. During this period receiving waters in Humboldt Bay had much higher total coliform levels than the waste water aquaculture ponds (Allen, 1973, Table III). Unchlorinated leachate from an adjacent sanitary land-fill waste disposal site was discharging to the adjoining estuary (Jolly Giant Creek located immediately west of the fish ponds). Values up to $1{\cdot}1 \times 10^5$ were recorded from Humboldt Bay waters adjacent to the land-fill outfall from November 1972 to March 1973 (Kunkel, 1973). The dump has since been abandoned and covered with impervious layers of bay muds so that coliforms now entering the Bay from this location would not be of human origin. Substantial coliform levels are still being recorded, however, in Humboldt Bay waters next to the fish culture ponds during winter periods. This is probably due to run-off from marsh and pasture lands, and from urban streams (*eg*, Jolly Giant Creek) (Table III).

Only routine sampling of pond waters prior to discharge into Humboldt Bay have been conducted since 1972. These have all given total coliform indexes which could be acceptable for a continuous discharge into an estuarine area used for bivalve production (Table III).

4.3.2 *Faecal streptococci.* Our first studies on faecal streptococci content of fish pond and other waters were from samples taken on four different days during 1975 (Table IV). It is difficult to assess the meaning of these data since little information exists on this parameter in local fresh waters discharging into Humboldt Bay or in Humboldt Bay waters themselves (Busch, 1975). There are, however, some general patterns that are obvious. First, faecal streptococci were always highest in the oxidation pond and in Jolly Giant Creek, and lowest in the fish ponds. Second, high levels of faecal streptococci were found in four recirculating aquaria initially supplied with pond water.

A possible rate of reduction of faecal streptococci in the fish ponds may be deduced from studies on 3 September 1974 (Table IV). The last introduction of oxidation pond waters into North Pond was on 14 August and the last pumping of North Pond water into South Pond was also on 14 August. Thus after about a two week retention of waste waters in these fish ponds, faecal streptococci levels were about the same as those found in the last four cells of fish cultivated in oxidation ponds at Quail Creek, Oklahoma (Carpenter *et al*, 1974).

The occurrence of very high levels of faecal streptococci in two separate recirculating tanks rearing coho salmon was completely unexpected (Table IV). These systems were placed in trial operation in May 1975 (see Section 5.3) to determine their holding capacity for fingerling salmonids (Larry Dennis, personal communication). A one foot (0·3 m) layer of pea gravel and dolomite over a false bottom is the only water-treatment device in these 1000 gal (3 790–1) units (the actual water volume was only about 850 gal or 3 210 1). These tanks had been filled with water from South Pond. This water was algae-laden and required about two weeks before it became crystal clear. Subsequent additions of pond water made to reduce nitrate levels in the tanks only required a few days before they cleared. On 17 November 1975, two additional units of the system (Tanks

TABLE III

TOTAL COLIFORM DETERMINATIONS IN ARCATA FISH PONDS AND ADJACENT WATERS[a]

Date sampled	*Oxidation Pond*	*North Pond*	*South Pond*	*Humboldt Bay*	*Jolly Giant Creek Upper Estuary*	*Other*	
						Value	*Description*
1973							
21 May		$2{\cdot}3 \times 10^1$	$2{\cdot}3 \times 10^1$				
29 Nov.	$1{\cdot}6 \times 10^1$	0·3 and $5{\cdot}4 \times 10^{2b}$	3·5 and $3{\cdot}5 \times 10^{2b}$				
1974							
21 Oct.	$<1{\cdot}6 \times 10^1$	$2{\cdot}4 \times 10^2$	$2{\cdot}78 \times 10^2$			$0{\cdot}2 \times 10^1$	Confluence of outlet ditch from fish ponds and tidal channel at low tide
7 May	$<1{\cdot}6 \times 10^1$	$3{\cdot}3 \times 10^1$	$0{\cdot}5 \times 10^1$			$>1{\cdot}61 \times 10^1$	North and Oxidation Pond muds
						$4{\cdot}6 \times 10^1$	South Pond mud
1975							
10 Jan.	$1{\cdot}61 \times 10^1$	$5{\cdot}4 \times 10^2$	$1{\cdot}7 \times 10^2$	$1{\cdot}6 \times 10^1$		$2{\cdot}8 \times 10^2$	Confluence of outlet ditch from fish ponds and tidal channel, high tide
						$5{\cdot}4 \times 10^2$	Drainage from marshes east of Oxidation Pond one hour after high tide
7 Mar.	$<1{\cdot}61 \times 10^3$	$3{\cdot}5 \times 10^2$	$1{\cdot}7 \times 10^1$	$4{\cdot}9 \times 10^1$			
18 April	$1{\cdot}61 \times 10^1$	$3{\cdot}3 \times 10^1$	$4{\cdot}9 \times 10^1$				
29 May	$(5{\cdot}75 \times 10^4)$	$(2{\cdot}70 \times 10^2)$			$(3{\cdot}1 \times 10^1)$	$(9{\cdot}7 \times 10^2)$	Jolly Giant Creek, inland about two miles (3.2 km)
3 Sept.	$2{\cdot}4 \times 10^1$ $(1{\cdot}8 \times 10^4)$	$2{\cdot}3 \times 10^1$ (0)	$1{\cdot}7 \times 10^1$ $(1{\cdot}0 \times 10^2)$		$2{\cdot}4 \times 10^1$ $(4{\cdot}5 \times 10^1)$		
17 Nov.	$>2{\cdot}4 \times 10^1$	$9{\cdot}2 \times 10^2$ $(4{\cdot}7 \times 10^2)$	$4{\cdot}9 \times 10^1$ $(4{\cdot}4 \times 10^1)$	$5{\cdot}4 \times 10^2$ $(9{\cdot}0 \times 10^2)$	$1{\cdot}6 \times 10^1$		

[a] Membrane filter (MF) techniques were initiated 29 May 1975. These values (MF counts/100 ml) are shown in parentheses. Values not shown in parentheses are Most Probable Number indices (MPN/100 ml)

[b] North pond had forced air aeration, South pond had one central spray aeration unit. Two samples were taken from different parts of each pond

3 and 4) were filled in sequence with water pumped from South Pond. Pond sediments were observed in the introduced water as the intake valve was near the pond bottom. Faecal streptococci levels were twice as high in water from the tanks as in South Pond waters (Table IV, 17 November sampling), indicating pond sediments as a possible reservoir for these forms. The source, mode of maintenance, and accumulation of such high levels of faecal streptococci in these recirculating tanks, as well as in pond sediments, need to be investigated further.

In November, faecal streptococci levels in North Pond had risen sharply over that found in September, while levels in South Pond had decreased (Table IV). The ranges of some physical and chemical parameters in these ponds for the 1–17 November period are shown in Table V. A major difference is the presence of very high concentrations of *Chlorella* in South Pond as compared to a lesser population of the diatom *Chaetoceros* in North Pond. South Pond phytoplankton population undoubtedly produced the differences in clarity, pH and oxygen levels between the two ponds. There appears a negative correlation between faecal streptococci levels and high phytoplankton populations. The negative correlation also held for total coliforms (Table III). A very slight seepage into North Pond occurs around the effluent intake pipe and through one portion of the dike. This might have been sufficient to inoculate the ponds and produce increasing levels of coliforms and faecal streptococci in the absence of high levels of pH and oxygen, or perhaps lack of exocrines due to lack of *Chlorella* populations.

The increase in faecal streptococci counts without the addition of waste water in North Pond was entirely unexpected. Conversely, the low values in South Pond under a higher density of fish and *Chlorella* supports the concept that highly fertile waste water ponds stocked with fish have a significant waste water renovation capacity (Allen and Hepher, 1979).

4.3.3 *Discussion.* The fish ponds at Arcata are drained during periods of incoming tides, consequently a large dilution is given to the effluent before an outgoing tide carries pond water into areas of shellfish production in north Humboldt Bay. This dilution rate may also protect the oyster beds from contamination by Jolly Giant Creek water; however, creek waters could easily reach the oyster beds during low tide periods by moving rapidly in confined tidal channels.

As human populations grow and result in increased waste waters draining to surface or underground water supplies, the degree of possible dilution of waste waters by natural waters will become reduced. Thus, the present total coliform and faecal coliform standards, which do not distinguish between those of human and those of other animal origin, or do not include infectious diseases commonly shared by and transmitted between lower animals and man, or of water-borne viruses (Janssen, 1970; Carpenter *et al*, 1974), will undoubtedly have to be replaced by more precise tests. This will, of course, be necessary to ensure protection of public health but also to prevent unnecessary measures against presumptive but innocent waste water dischargers (Busch, 1975). For example, the major source of coliforms in Humboldt Bay is the adjacent pastures used for raising beef and dairy cattle, not waste water treatment plants (California State Department of Public Health, 1973

TABLE IV

TOTAL FAECAL STREPTOCOCCI FOUND IN ARCATA WASTEWATER FISH PONDS AND ADJACENT WATERS, MAY AND NOVEMBER 1975 (ALL VALUES, NO./100 ML, AS DETERMINED BY MEMBRANE FILTER (MF) TECHNIQUES)

Sampling location	*Date of sampling*			
	29 May	*3 Sept.*	*8 Sept*	*17 Nov.*
Oxidation Pond	$1{\cdot}10 \times 10^{3}$	$4{\cdot}0 \times 10^{2}$	—	—
North Fish Pond	$1{\cdot}12 \times 10^{3}$	$1{\cdot}0 \times 10^{2}$	—	$7{\cdot}6 \times 10^{2}$
South Fish Pond	[a]	$1{\cdot}0 \times 10^{2}$	—	$4{\cdot}0 \times 10^{1}$
Jolly Giant Creek	$2\ 00$–$4\ 50 \times 10^{2}$	$2{\cdot}0 \times 10^{1}$	—	—
Recirculating aquaria (with gravel filters):				
Tank 1	—	$7{\cdot}0 \times 10^{3}$	$2{\cdot}2 \times 10^{4}$	—
Tank 2	—	—	$2{\cdot}4 \times 10^{3}$	—
Tank 3	—	—	—	$2{\cdot}2 \times 10^{2}$
Tank 4	—	—	—	$1{\cdot}0 \times 10^{2}$
Sanitary landfill leachate (after covering with clay and abandoning operations)	$6{\cdot}00 \times 10^{1}$	—	—	—

[a] A communications gap resulted in South Pond being drained before a water sample was taken

TABLE V

RANGE IN VALUE OF SELECTED PARAMETERS, 1–17 NOVEMBER 1975, IN ARCATA WASTE WATER FERTILIZED FISH PONDS

Parameter	*North Pond*	*South Pond*
Salinity (ppt)	12–13	20–22
Clarity (Secchi disc, disappearance in cm)	38–120+	22–27
pH	7·7–8·7	7·9–8·4
Oxygen (mg/l)	4·4–13·6	9·0–14·8
Colour (naked eye)	Light brown	Yellow green
Phytoplankton[1] (95% dominance)	*Chaetoceros*	*Chlorella*
Fish population	1 800 rainbow trout (15 cm) 500 kokanee salmon (8 cm)	30 000–40 000 coho salmon (10 cm)

[1] Identification by Dr. W. C. Vinyard, Department of Botany, Humboldt State University

and 1973a; Beilfuss, 1967). Moreover, it may be impossible to locate leakages from old sewer mains into natural water courses or replace the mains if located. Estuaries are, however, adapted to additions of fresh water. Discharge of waste waters to the ocean merely transfers any potential harm to humans from zoonoses to salmon, flatfish, and crab populations in the area of the proposed ocean outfall where sport and commercial fisheries harvest and process these animals for consumption.

5. Fish diseases

5.1 *Introduction*

All species and sizes of salmonids commonly reared along the Pacific coast of North America, either in saltwater or brackishwater environments, have been subject to heavy losses due to vibriosis, a bacterial infection seemingly worldwide in occurrence (Ross, Martin and Bressler, 1968; Anderson and Conroy, 1970). Fish susceptible to these bacteria generally show a haemorrhagic septicaemia pathology in acute stages of infection. Subacute or chronic infections are commonly characterized by dermal petechial haemorrhage, bloody abscesses and ulcerations. Once the disease has become established, up to 95–98% of an infected population can die within a few days.

Reporting of our initial isolations of this fish pathogen in the Arcata system, along with associated mortalities, seems appropriate to a discussion of possible therapeutic effects of waste water systems for fish. Janssen (1970) has discussed the theoretical possibilities of such mechanisms in waste waters treated in oxidation ponds.

5.2 *Initial isolation of vibriosis*

The first confirmed isolation in September 1974 was made of *Vibrio anguillarum* in the pond-reared salmonids at the end of a summer rearing experiment. A total of 110 steelhead trout recovered from pens in South Pond (Allen, 1975) were examined for gross pathological conditions. One steelhead trout showing exophthalmia and oedema was found to be infected with *V. anguillarum*. The steelhead trout in this experiment had been pen-reared for 79 days. These fish showed a 26% survival over this period, with mortalities primarily occurring in September. Pond water temperatures at this time were about 19°C and declining (Allen, 1975).

5.3 *Vibriosis in filtered and unfiltered pond waters*

In early September 1975, *Vibrio anguillarum* was isolated as the causative agent of an epizootic in fingerling coho salmon reared in 1000 gal (3 790 l) closed recirculating aquaria originally charged with waste water-sea water mixtures from South Pond. These tanks were fitted with false bottoms covered with 1 ft (0·3 m) of mixed pea gravel and dolomite pellets.

The history of salmonids in these tanks follows. Initial water from waste water ponds was introduced into two tanks in mid-May 1975. It took about two weeks before the highly algae-laden pond water became crystal clear. The water remained in one unit (Tank 1) until 22 and 29 August when part of the tank water was replaced with water from North Pond to reduce nitrate concentrations. From 13 May until 19 June, 11400 coho salmon fingerlings were incrementally added to Tank 1 to test for oxygen levels under increasing loads of fish, and to test the efficiency of the filter beds to convert ammonia and nitrites into nitrates. In late June, 2000 of these fish were removed to a second aquarium (Tank 2) where previously several hundred yearling steelhead plus a few coho and chinook salmon were being held. By mid-August, all 2000 fingerling coho had died, together with most of the larger steelhead, coho, and chinooks. The cause of this mortality was not determined but there is a possibility that the fish became stressed from an undiscovered accidental reduction in air pressure in a line operating the tank's aeration system.

From mid-May until early September losses in coho fingerlings in Tank 1 were only one or two fish per week. On 4 September, 22 losses occurred; on 5 September, 400; on 6 September, 405. Moribund and lethargic fish showed haemorrage oedema and scale loss primarily along the lateral line. Bacterial studies confirmed *Vibrio anguillarum* as the causative agent. Treatment, consisting of Terramycin (4.5 mg/45 kg of fish/day) added to a diet of Oregon moist pellets, was begun on 6 September. By 10 September 1975, losses had dropped to only 35 fish/day. Due to immediate diagnosis and treatment, total losses were only 10% of the population after a 15 day treatment period. This correlates with reduction of losses to around 10% in marine-cultured coho salmon in Oregon administered an intraperitoneal killed vibrio vaccine (Novotny, Harrell and Nyegaard, 1975).

During the summer of 1975, steelhead fingerlings being reared in North Pond had suffered losses attributed to abrupt changes in pond chemistry during late July. About half of 25 fish being reared in a 'live car' survived this period. All of these fish were in good condition in early October (at the time of preparation of this paper), thus not suffering the excessive losses from vibriosis recorded for fish reared in the recirculating aquaria in filtered pond water.

5.4 *Vibriosis in kokanee salmon*

On 23 October 1975, approximately 2000 kokanee salmon from Trinity Reservoir (on the Trinity River in northern California) averaging 75 mm fork length were planted into North Pond. On 30 October, 16 recently dead or dying kokanee which were collected were found to be suffering from vibriosis. Scattered mortalities were noted in this pond until 7 November, but actively feeding kokanee were observed until pond drainage on 17 November 1975 when 37% of the fish were recovered. Lots of 50 kokanee salmon reared in 4 m^2 pens in the same pond over mud, shell, and gravel substrates had survivals of 68–94%. This increased survival rate associated with salmon reared in pens in a pond of fish affected by an epizootic cannot be explained. We have had consistently higher survivals of pen-reared fish than of the same fish reared in ponds, although their growth rates have been slower than those of pond-reared fish. Kokanee used in this experiment may be a stock of salmonids particularly susceptible to vibriosis since this form completes its life cycle in fresh water rather than going to sea. Isolation from the sea is total in the kokanee population from the Trinity Reservoir as no fish passage facilities exist around Trinity Dam.

5.5 *Discussion*

Allen and O'Brien (1967) reported an unexplained therapeutic effect on fall chinook salmon juveniles by waste water-fertilized sea water during a series of two-week

bioassays. Chinook and coho salmon, and steelhead trout, reared in South Pond during the summer of 1974, showed fairly high survival rates at the time companion lots of fish were suffering heavy losses from diseases in local hatcheries (Allen, 1975). Mass mortalities of salmonids in the Arcata system have been related to factors other than disease, although specific concurrent studies on disease were not available (Allen and Dennis, 1974; Allen and Carpenter, 1975).

That there appears to be some beneficial effect on fish health of salmonids reared in mixtures of oxidation pond effluent and sea water in the Arcata ponds continues to be supported by at least two further results: (*i*) the high mortalities of vibrio-infected coho salmon reared in closed-recirculating systems (filtered pond waters) as compared with those of steelhead trout in adjacent ponds; and (*ii*) the relatively high survival rates of vibrio-infected pond-reared kokanee salmon not receiving any therapeutic treatment. No explanation could be found for these results. It is possible that strains of the two species had different susceptibilities to vibriosis, but it is also possible that the biotic community of the sea water-oxidation pond effluent mixture provided some protective mechanism to the salmonids which was removed after filtration in the fish tanks. Algal removal was a major gross change noted in the filtered pond waters.

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Utilization of Heated Discharge Water from Electric Power Plants in Aquaculture

J. Tanaka

Abstract
Cooling water from electric power generating plants in Japan is discharged in large volumes at temperatures averaging about 7°C above ambient water temperatures. Research in Japan on the utilization of heated discharge water in aquaculture, which began about 15 years ago, has shown its utilization to be very beneficial both in seed production of such species as the abalone (*Haliotis discus hannai*) and red seabream (*Pagrus major*), and also in rearing kuruma shrimp (*Penaeus japonicus*), yellowtail (*Seriola quinqueradiata*) and others. These species show increased rates of food consumption resulting in more rapid growth rates when cultured at higher water temperatures. Furthermore the increased food conversion efficiency at higher water temperatures is of special significance in rearing these species.

Facilities for onshore rearing with heated water are expensive, and the use of floating pens located in the discharge water outfall is recommended for large-scale culture enterprises. It is considered that use of heated discharge water may have important application in aquaculture development for production of eggs and seed stock, and for rearing of culture organisms to adult size.

Utilisation en aquaculture des effluents thermiques des centrales électriques
Résumé
Au Japon, l'eau de refroidissement des centrales électriques est rejetée en grandes quantités à des températures supérieures de 7°C en moyenne à celles de l'eau ambiante. Les recherches faites dans ce pays sur l'utilisation en aquaculture des effluents thermiques se poursuivent depuis une quinzaine d'années; cette utilisation s'est révélée très utile aussi bien pour la production de naissains d'espèces telles que les ormeaux (*Haliotis discus hannai*) et d'alevins de "tai" (*Pagrus major*), que pour l'élevage de la crevette kuruma (*Penaeus japonicus*), de la sériole (*Seriola quinqueradiata*), *etc.* La consommation alimentaire de ces espèces a augmenté dans des eaux à température plus élevée, leur taux d'accroissement s'accélérant en conséquence. L'augmentation de l'efficacité de la conversion des aliments en eau à température élevée revêt un intérêt spécial pour l'élevage de ces espèces.

Le coût des installations pour l'utilisation des effluents thermiques dans des élevages sur la côte est élevé: il est recommandé aux grandes entreprises piscicoles d'employer des cages flottantes immergées près du déversoir. On pense que l'utilisation des effluents thermiques pourrait trouver d'importantes applications en aquaculture pour la production de naissain, d'oeufs et d'alevins, ainsi que pour l'élevage des jeunes jusqu'au stade adulte.

Utilización para la acuicultura de las aguas cálidas descargadas por las centrales eléctricas
Extracto
En el Japón, las aguas de enfriamiento de las centrales eléctricas se descargan en grandes cantidades a temperaturas superiores en unos 7°C a la temperatura ambiente del agua. Las investigaciones sobre la utilización de estas aguas cálidas en la acuicultura comenzaron en el Japón hace unos 15 años y han mostrado que su empleo es muy beneficioso para la producción de semilla de especies como el abalone (*Haliotis discus hannai*) y el besugo (*Pagrus major*) y para la cría de camarón kuruma (*Penaeus japonicus*), pez limón (*Seriola quinqueradiata*) y otros. En todas estas especies, cultivadas en agua a temperatura más elevada, se observa un aumento del índice de consumo de alimentos, que da como resultado tasas más rápidas de crecimiento. En la cría de estas especies, sin embargo, es especialmente importante el hecho de que al aumentar la temperatura del agua aumenta también la eficiencia de la conversión de los alimentos.

El costo de las instalaciones para la cría en zonas costeras con aguas cálidas es elevado y para el cultivo a gran escala se recomienda el empleo de recintos flotantes situados en el lugar de descarga de las aguas. El empleo de estas aguas cálidas puede tener aplicaciones importantes en el desarrollo futuro de la acuicultura, tanto para producir huevos y material para siembra como para criar los organismos hasta la edad adulta.

1 Introduction

Attempts are being made in various countries to use the cooling water discharged from electrical power generating plants for aquaculture, and in some places commercial culture of aquatic organisms in heated effluents has already been undertaken. In Japan, research in this field was initiated about 15 years ago, and in all but one case marine species have been the main concern. This is because there are few large lakes or rivers in Japan to supply cooling water for power plants, and sea water is used almost exclusively for this purpose.

In 1964, rearing experiments were carried out with parrot bass (*Oplegnathus fasciatus*) in wire mesh pens floated in the discharge canal at the Yokosuka Thermal Power Station of the Tokyo Electric Power Company. In 1965, good results were obtained with experimental rearing of yellowtail (*Seriola quinqueradiata*) in ponds utilizing discharge water from the Owasemita Thermal Power Station of the Chubu Electric Power Company. In 1971, at the request of the Science and Technology Agency of Japan and the Japan Fisheries Resources Conservation Association, culture ponds totalling 2 040 m^2 were constructed on the grounds of the Japan Atomic Energy Research Institute, and rearing experiments using these facilities were undertaken with kuruma shrimp, *Penaeus japonicus*, red porgy, *Evynnis japonica*, and other species.

The late Dr. T. Imai conducted research on oyster culture using heated discharge water about 15 years ago at the Sendai Thermal Power Station of Tohoku Electric Power Company, and seed of the abalone, *Haliotis discus hannai*, is now being produced there. In addition, seed production and culture to marketable size of various marine organisms is being undertaken at a number of power plants throughout Japan.

2 Fish and shrimp culture

The temperature of discharge water of power plants in Japan is ordinarily 6 to 10°C (7°C on the average) warmer than the ambient seawater temperature. Many different species have been reared using heated discharge water, each within the optimum temperature range for the species. Of these, the rearing of yellowtail at the Owasemita Thermal Power Station and of kuruma shrimp at the Tokai Farm of the Japan Thermal Aquaculture Development Society are described here.

2.1 *Yellowtail*

2.1.1 *Facilities.* The main pond at Owasemita is constructed of cement, is octagonal in shape, has a diameter of 10 m and operates at a water depth of 2·5 m at the centre decreasing to 1·5 m at the periphery. The capacity of the pond is 143 m^3. Water is supplied from a pipe crossing above the pond, with jets directed to create a circular water flow; drainage is from the centre of the pond. The rate of flow is 100 m^3/h, giving a water replacement rate of 70 %/h.

Heated water is pumped from the discharge canal of the power plant to a tank in which it is first mixed with sea water at ambient temperature before being supplied to the rearing pond. However, when the temperature of coastal water rises above 20°C, only natural sea water is pumped to the mixing tank from a well. This well is located behind a sea wall, and sea water enters it by seepage. Fig. 1 shows daily variation in temperature in the pond and in ambient sea water, as well as daily variations in specific gravity and dissolved oxygen concentration of the pond water.

2.1.2 *Results.* Yellowtail (average weight 625 g) were released in the pond on 21 September 1965. They were fed

such foods as anchovy, horse mackerel and saury. The growth curve for yellowtail used in this experiment is shown in Fig. 2a as well as growth curves of yellowtail reared at ambient seawater temperatures in floating pens by a commercial culturist and at a prefectural fisheries experimental station. The yellowtail reared in the pond under controlled temperature conditions continued to grow at a rapid rate during the winter season when the growth rates of the yellowtail reared in the sea decreased. Daily growth rates, feeding rates and food conversion efficiency rates of the three groups of fish are shown in Fig. 2. For the fish reared in the heated water, maintenance of high water temperatures during the winter resulted in high food conversion efficiency in addition to continued feeding activity and high growth rates. The use of heated discharge water in the commercial rearing of yellowtail therefore not only promotes growth, but has a wide range of other effects from reducing feeding costs to altering management procedures.

2.2 *Kuruma shrimp*

2.2.1 *Facilities.* The Tokai Farm of the Japan Thermal Aquaculture Development Society has 34 indoor rearing tanks totalling 2 040 m^2 in area. Of these, 16 tanks are $6 \times 10 \times 2$ m deep and 18 tanks are $6 \times 10 \times 1{\cdot}5$ m deep. There are also four outdoor tanks: two are decagonal and two are circular, all have a diameter of 10 m and total 314 m^2 in area. There are also six indoor circulating tanks made of fibreglass and measuring $3 \times 1 \times 1$ m deep. The tanks can be supplied with 18 m^3 of heated discharge water per minute by the Japan Atomic Power Company's Tokai Power Plant.

2.2.2 *Results.* Because the shrimp seed had to be transported by air from the Fujinaga Kuruma Shrimp Institute in Yamaguchi Prefecture, small seed (P20) initially weighing 2·5 mg were used. The shrimp were fed mainly artificial feed and sometimes mysids. The growth results from this experiment are shown in Fig. 3, together with the growth curve of kuruma shrimp reared on a shrimp farm in western Japan. The growth curves were nearly the same in both cases.

Insufficient experience has been gained in rearing kuruma shrimp at the Tokai Farm, and more data are needed on the use of heated discharge water during the winter season. From the data that have been collected at the Tokai Farm, it is apparent, however, that tank water temperatures can be maintained above 18°C during the winter (Fig. 3). Kuruma shrimp are rarely caught along the coast of Ibaragi Prefecture where the Tokai Farm is located, and up to now this species has not been cultured in this area. The kuruma shrimp rearing effort at the Tokai Farm provides, therefore, an example of the culture of a species using heated discharge water in an area in which it is not naturally abundant.

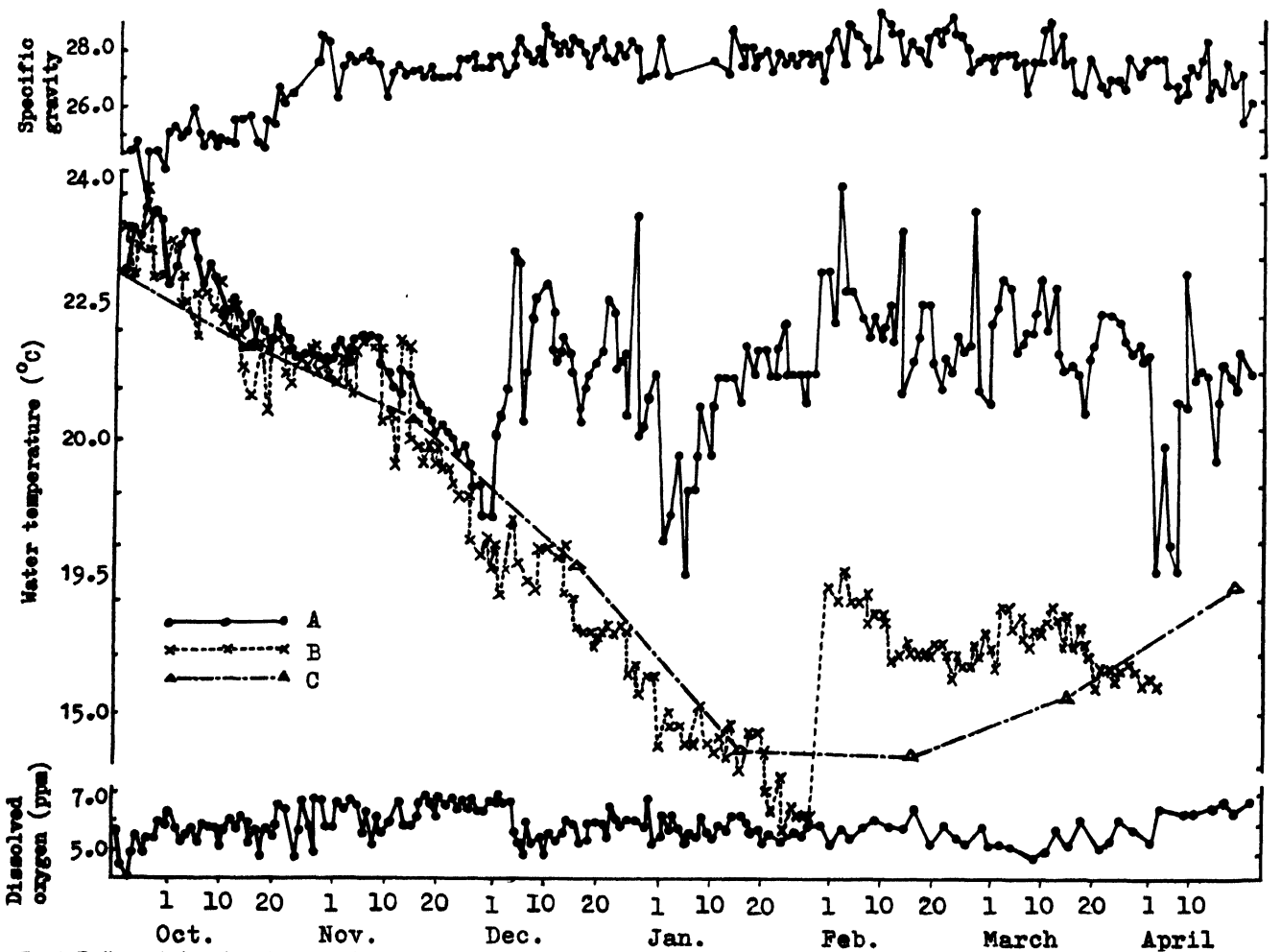


Fig 1. Daily variations in culture pond conditions and ambient seawater temperature during the rearing of yellowtail. A. Pond water conditions. B. Ambient seawater temperature (Prefectural Fisheries Experimental Station). C. Ambient seawater temperature (commercial culturist)

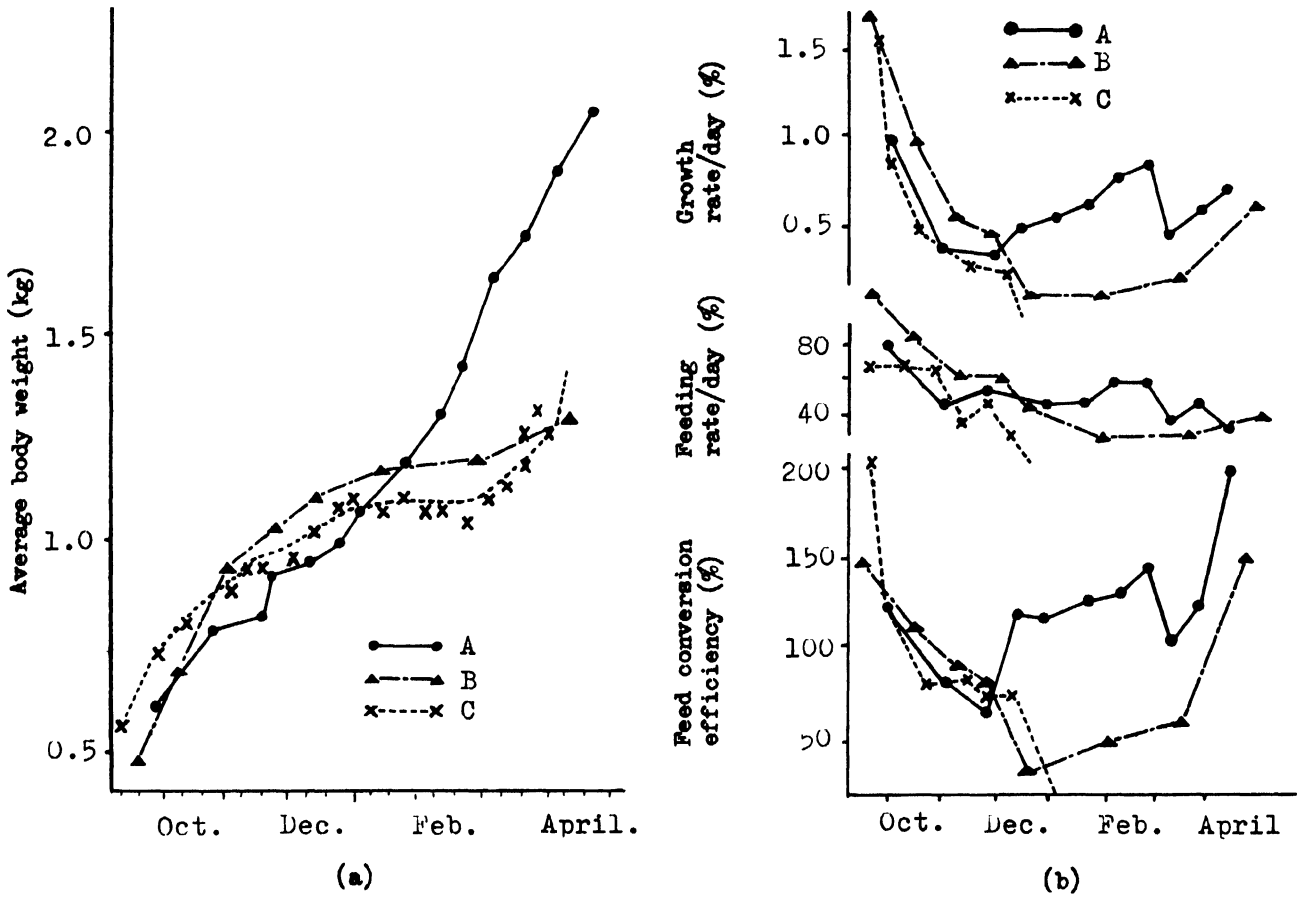


Fig 2. Growth curves, daily growth and feeding rates, and feed conversion efficiency of three groups of cultured yellowtail. A. In pond warmed with discharge water B. In the sea (Prefectural Fisheries Experimental Station). C. In the sea (commercial culturist)

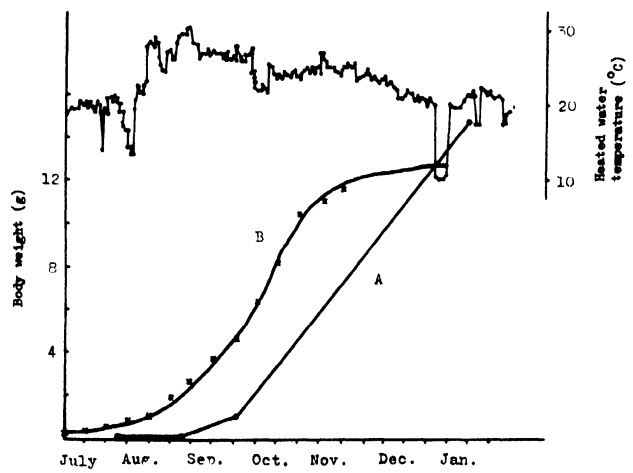


Fig 3. Rearing data for cultured Kuruma shrimp. A. Growth in ponds warmed with discharge water. B. Growth in natural sea water.

3 Seed Production

In recent years, techniques for mass production of seed both for pond culture and sea farming have been developed and put into practice in Japan. The use of heated discharge water in the production of seed has proved successful in shortening the time required to rear fish and other aquatic organisms to maturity, making early egg collection possible. In addition, the time required to rear larvae to adequate seed size can also be reduced. As examples of what has been accomplished, the early collection of eggs of red seabream (*Pagrus major*) and the accelerated production of the seed of the abalone (*Haliotis discus hannai*) are described below.

3.1 *Spawning of red seabream*

3.1.1 *Facilities.* The pond used to rear red seabream to early maturity was the same as that described previously for the rearing of yellowtail at the Owasemita Thermal Power Station (section 2.1.1). Nine males and 27 females, were released into this pond.

3.1.2 *Results.* The spawning season of red seabream in the coastal waters of Mie Prefecture in Japan extends from April to June, with its peak in May. Red seabream which were reared using heated discharge water to maintain high water temperatures began to spawn on 11 February in 1973 and on 19 March in 1974. A total of 8900000 fertilized eggs were collected in 1974. Thus, the spawning season began up to two months earlier than in the natural environment, and its length increased from two months

under natural conditions to as long as four months. An increase in the length of the spawning season increases to the same extent the opportunity for egg collection. Furthermore, a greater number of eggs can be obtained, and fry can be produced at least twice a year in the same facilities.

3.2 *Accelerated production of abalone seed*
Abalone seed has been produced since 1967 at the Sendai Thermal Power Station of the Tohoku Electric Power Company.

3.2.1 *Facilities.* Up to 1970, rearing tanks measuring 5·0 × 0·6 × 0·45 m deep were contained within temperature control tanks 6·0 × 1·5 × 0·5 m deep. One hundred 33 × 40 cm sheets of vinyl chloride were immersed in each rearing tank. Heated discharge water was pumped first to a mixing tank and then supplied to each rearing tank at a rate of about 30 l/min. To expand the scale of seed production, 15 canvas rearing tanks, 20·0 × 1·5 × 0·5 m deep, have been added since 1971. Sixteen sets of 25 corrugated vinyl chloride sheets are immersed in each of these tanks. Water is supplied to each tank at the rate of 100 m^3/h, and a single aeration system with a total capacity of 4 m^3/min has been provided for all the tanks.

3.2.2 *Results.* The growth curves for abalone larvae reared during the winter using heated discharge water and during the summer when discharge water was not needed are shown in Fig. 4, together with the corresponding growth curves of abalone larvae in their natural environment. During winter, the shell length of cultured abalone larvae increased by more than three times the increase in shell length of naturally occurring larvae over the same three-month period. The summer growth curves are not significantly different; rapid growth occurred in both cases.

In addition to accelerating larval growth, the use of heated discharge water in abalone seed production increases the propagation rate of the diatoms upon which abalone larvae feed.

4 Discussion

In Japan the discharge water from power plants is pumped from the discharge canal up to the culture ponds. As a result, the cost of electricity to operate the pumps significantly increases culture expenses. However, because the discharge water ordinarily flows at a high rate, its physical energy can be used to elevate water to pond level by narrowing the channel of flow. Pumping costs can thus be kept to a minimum.

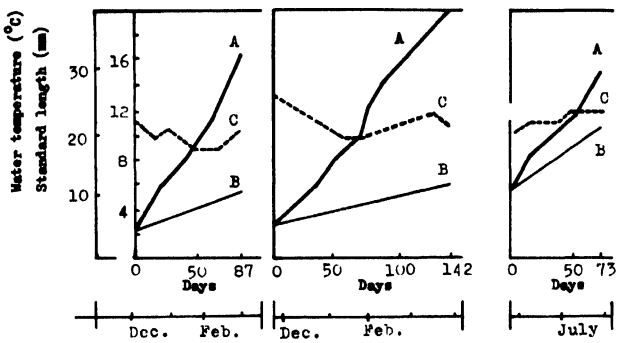


Fig 4. Growth of abalone larvae
A. In ponds warmed with discharge water
B. In the sea (naturally occurring abalone)
C. Pond water temperature

A relatively large investment in facilities is necessary to build ponds for land-based culture. This is especially true when marine species are cultured because roofs must be built over the ponds to control the growth of seaweeds and other marine organisms. Due to these costs, it is necessary to culture relatively high-priced species at high densities.

For large-scale culture, the use of floating sea pens located in the discharge water outfall has more potential.

5 Conclusion

Specific examples of the use of heated discharge water in marine aquaculture have been described. The results of this and other research indicate that the use of heated discharge water may have important application in aquacultural development as summarized below:

Application	*Possible benefits*
Egg production	Early maturity of broodstock, with consequent early egg collection Egg collection throughout the year Reliable method for rearing broodstock
Seed production	Increased rate of fertilization Shorter incubation period Increased hatching rate Shorter larval rearing period Mass culture of food organisms
Rearing	Increased growth rate Increased food conversion efficiency Development of comprehensive management techniques in environment control systems

Preliminary Fish Farming Experiments in Brackishwater Thermal Effluents

H. Kuhlmann

Abstract
An experimental fish farming station on the northern coast of the Federal Republic of Germany supplied with heated brackish cooling water from a conventional power plant is described. The station consists of 15 tanks (mostly made of fibreglass) ranging in size from 1·5 to 50 m^3. At full operation, a flow of 100 l/sec is available. Temperature and salinity fluctuate seasonally from about 14° to 30°C and 4–18 ppt respectively.

Experiments in 1975 concentrated on rearing rainbow trout and European eel. Temperature being a limiting factor for rainbow trout, this species could be cultured here only during winter. Trout of 50 g, fed on pellets, reached marketable sizes of 250–300 g within 3–4 months with a feed conversion of about 2:1. Eels could be reared from 20 g size to marketable sizes of 180–250 g within 1–2 years. It would require 6–8 years for eels to attain this growth in natural inland waters of the country. Bacterial diseases in both eel and trout were successfully treated with antibiotics.

The seasonal fluctuations of temperature and salinity in 1975 were not tolerated by the following species: plaice, flounder, turbot, sole, pike-perch, common carp, sheat fish, grass carp, and coho salmon. Some warmwater fish species, such as mullet, sea bass, rabbit fish and tilapia could be kept under the special brackishwater conditions.

Expériences préliminaires de pisciculture dans les eaux saumâtres d'effluents thermiques

Résumé
L'on décrit dans cette communication une station piscicole expérimentale située sur la côte nord de la République fédérale d'Allemagne et alimentée par des eaux saumâtres réchauffées provenant du refroidissement d'une centrale thermique du type classique. La station comporte 15 réservoirs (fabriques pour la plupart en fibre de verre) dont la taille s'échelonne de 1·5 à 50 m^3. En pleine marche, le débit atteint 100 l/sec. La température et la salinité de l'eau accusent une variation saisonnière de 14 à 30°C et de 4 à 18 parties pour mille respectivement.

Les expériences menées en 1975 ont porté essentiellement sur l'élevage de la truite arc-en-ciel et de l'anguille. La température constituant un facteur limitatif pour la truite arc-en-ciel, cette espèce n'a pu être élevée dans la station que pendant l'hiver. Des truites de 50 g, nourries avec des granulés, ont atteint des tailles marchandes de 250 à 300 g en une période de 3 à 4 mois, avec un taux de conversion des aliments voisin de deux. On a pu amener des anguilles de 20 g à des tailles marchandes de 180 à 250 g en une période de 1 à 2 ans. A l'état naturel, il faudrait de 6 à 8 ans pour que les anguilles atteignent cette croissance dans les eaux intérieures du pays. L'on a traité avec succès des maladies bactériennes tant chez l'anguille que chez la truite au moyen d'antibiotiques.

Les fluctuations saisonnières de la température et de la salinité survenues en 1975 n'ont pas été tolérées par les espèces suivantes: plie, flet, turbot, sole, sandre, carpe commune, silure, carpe chinoise et saumon argenté. L'on a pu conserver certaines espèces des eaux plus chaudes, telles que le mulet, le bar, les siganidés et le tilapia, dans les conditions spéciales présentées par les eaux saumâtres.

Experimentos preliminares de cría de peces en aguas salobres de efluentes térmicos

Extracto
Se describe una estación piscícola experimental instalada en la costa septentrional de la República Federal de Alemania y abastecida con aguas salobres cálidas procedentes del sistema de enfriamiento de una central eléctrica de tipo tradicional. La estación consta de 15 tanques (principalmente de fibra de vidrio) de 1·5 a 50 m^3. Cuando funciona a pleno ritmo, el flujo de agua es de 100 l/seg. La temperatura y la salinidad fluctúan según las estaciones entre 14 y 30°C y 18 ppt, respectivamente.

Los experimentos realizados en 1975 se concentraron en la cría de trucha arco iris y anguila. Dado que la temperatura constituye un factor limitante para la trucha arco iris, solo puede ser posible cultivar esa especie durante el invierno. Alimentando a truchas de 50 g con alimentos granulados se obtuvieron truchas de 250–300 g en 3–4 meses, con un índice de conversión de piensos del orden de dos. En el plazo de 1–2 años, anguilas de 20 g alcanzaron tallas comercializables de 180 a 250 g. Para que las anguilas alcancen esa talla en las aguas continentales naturales del país son necesarios de 6 a 8 años. El tratamiento de las enfermedades bacterianas de la anguila y la trucha con antibióticos dio resultados satisfactorios.

Las fluctuaciones estacionales de la temperatura y la salinidad en 1975 no fueron toleradas por las siguientes especies: solla, platija, rodaballo, lenguado, lucio-perca, carpa común, silúrido *Silurus glanis*, y salmón coho. Algunas especies de peces de agua dulce, como múgil, perca de mar, siganidés y tilapia podrían mantenerse en esas condiciones especiales de aguas salobres.

1 Introduction

Search for new methods of aquaculture which can be used locally is an important field of fishery research in the Federal Republic of Germany. Although the country is located in a temperate climatic zone, relatively unsuited for the culture of fast-growing warm water fish species such as carps and eels, it has heated water effluents from power stations and other industries that offer excellent potential for aquaculture development.

In 1975, an experimental fish farm was established by the Institut für Küsten-und Binnenfischerei at the outlet of a conventional power plant located in the harbour area of Emden. The project, funded by the Federal Ministry for Research and Technology, Bonn, was started primarily to study the problems involved in utilizing this artificial warmwater potential for fish farming. One question was to determine which of the indigenous and non-indigenous fish species available to the Institute could be grown under the special brackishwater conditions of the Emden fish farm and how they could be farmed commercially. Although the first experiments were only started in January 1975 and the station not completed until July 1975, a number of useful observations were made, which are described below. The paper also includes some results obtained from a small commercial fish farming unit which has operated for two years in the neighbourhood of the experimental station and received continuous advice from the Institute. The information presented here is considered to be preliminary.

2 Description of the experimental station

The experimental fish farm was built in Emden, a city on the estuary of the River Ems, which flows into the North Sea. The station is supplied with cooling water from a conventional four-block power plant at Emden harbour. The power plant draws cooling water from the harbour at a rate up to 28 m^3/s and releases it into the harbour through an open channel. The harbour itself is connected with the River Ems only by sluices so that its water is rather stagnant. Temperature and salinity fluctuate seasonally.

The experimental farm station is supplied with water from the cooling water channel by means of three submerged pumps with capacities of 20, 30 and 50 l/s in order to adjust the pumping capacity economically to varying situations at the station. The water is pumped into a container of 12 m^3; from there it flows by gravity through pipes into individual tanks. The water level in the tanks is regulated by means of swivel-tubes, from which the water falls into a concrete raceway before flowing back into the channel. Each tank has a separate water supply and aeration facility.

Most of the tanks are made of fibreglass in order to facilitate technical variations, but two tanks consist of a metal frame lined with a hanging plastic sheet. The latter, being cheaper than the others, were acquired to test their suitability for fish farming.

Six types of tanks, ranging in size from about 1·5 to 50 m^3 are in use:

(*i*) Two square fibreglass tanks
2·0 × 2·0 m, 0·4 m deep
(*ii*) Four rectangular fibreglass tanks
0·8 × 3·5 m, 0·8 m deep
(*iii*) Two rectangular fibreglass tanks
2·0 × 6·0 m, 1·0 m deep
(*iv*) Three circular fibreglass tanks
6 m in diameter, 1·0 m deep
(*v*) Two circular fibreglass tanks
8 m in diameter, 1·2 m deep
(*vi*) Two circular tanks (plastic sheet)
7 m in diameter, 1·0 m deep

The concrete channel can be separated into sections to serve as additional units for holding, grading and rearing fish. Laboratory facilities are available. Water quality is continuously monitored by an automatic system.

3 Water temperature and salinity

In passing through the power station the water temperature is raised by about 10°C. In 1975, the monthly mean water temperatures fluctuated between 15°C in February and 29°C in August. Monthly minimum and maximum values differed by about 2–3°C from mean values. Daily fluctuations did not exceed in general 2–3°C (Fig. 1). Due

to the extraordinary summer temperatures in 1975 the absolute maximum temperature was 34·8°C. Since the winter of 1974/75 was extremely warm, winter temperatures might be considerably lower in future years.

The salinity of the cooling water is influenced by the salinity of the River Ems at Emden and by the quantity of fresh water flowing into the harbour through small inlets. In 1975, the lowest salinity of 5–6 ppt was observed from January to June, the months of highest rainfall. The salinity rose to 15–18 ppt from August to October (Fig. 1).

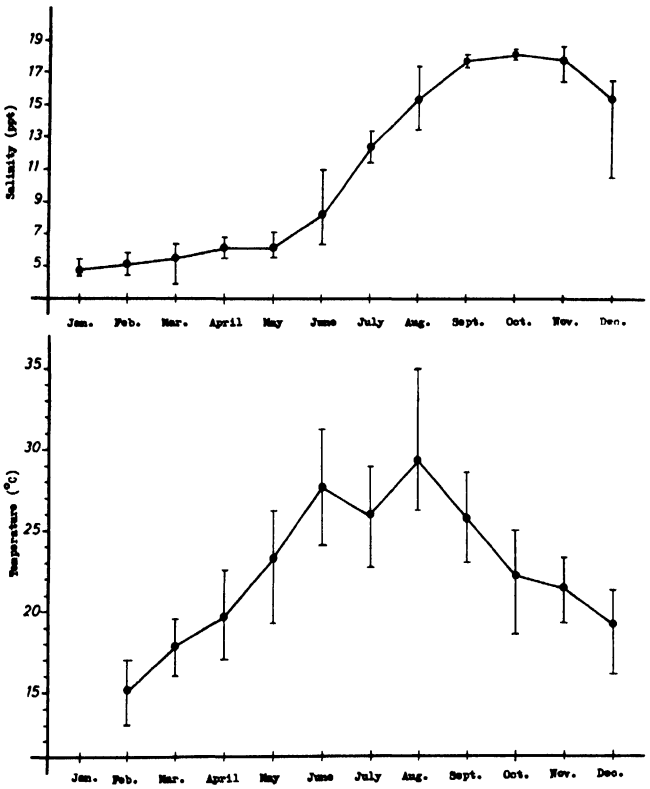


Fig 1. Mean, maximum and minimum salinities and water temperatures of effluent from Emden Harbour thermal power plant, 1972

4 Fish species tested

4.1 *Rainbow trout (Salmo gairdneri)*

Rainbow trout were found to be most suitable for farming under the given conditions, but only during the December–February period at water temperatures below 22°C. As rainbow trout can easily withstand salinities of 20 ppt (Koops, 1972), temperature has been found to be the only limiting factor here. Within three to four months, fingerlings of 50 g grew to marketable sizes of 250–300 g and fish of 3 g grew to 30 g.

Corresponding to experiences gained in cage farming of trout, stocking density in these experiments was 60 fish/m^3. This density was reduced to 15–20 kg/m^3 as the fish approached marketable size.

At a temperature of about 17–18°C, the fish were fed with commercial trout feeds at a rate of 2–3% of body weight per day. The feed conversion ratio (g feed:g gain) was about 2:1.

Outbreaks of diseases with symptoms of furunculosis were treated successfully by feeding medicated commercial trout feeds for a period of three days.

4.2 *Eel (Anguilla anguilla)*

Eels averaging 20 g in weight, farmed in concrete ponds covering 180 m^2 at the commercial farm near the experimental station could be grown to marketable sizes of 180–250 g in from one to two years. After eight months, 30% of the eels (50% of the total weight) could be sold. Annual eel production amounted to 10–15 kg/m^2.

At the Institute's experimental station, the eels were first fed with minced fish and brown shrimp (*Crangon crangon*). Later, industrial eel food was offered. At temperatures of 23–28°C the eels foraged wet food at a daily rate of 12–16% of their body weight. A mixture of 50% industrial eel food and 50% water was taken by the eels at a daily rate of 6–9%. Food intake decreased sharply at water temperatures above 29°C and below 20°C.

On the basis of the observations so far, it can be concluded that under normal temperature conditions eel mortality can be kept low if the initial stocking is at a density of about 2 kg/m^2. After one month of adaptation, the stocking density can be increased to at least 5 kg/m^2, which obviously influences the feeding behaviour and food intake of the eels.

Monthly eel mortality averaged 3% (0·8–7·2%) and was independent of the stocking density (2·0–4·5 kg/m^2). In only one experiment, with a stocking density of 5 kg/m^2 and at temperatures above 32°C, was mortality extremely high (23·1%) due to a massive outbreak of diseases. In the first case in October, this disease was immediately treated with Chloramphenicol (150 mg/kg eel/day) mixed into the food. Only a few losses occurred.

In the second case in November the eels were treated with Trafigal no earlier than 10 days after the first observation of diseased fish. Although Trafigal was used at a concentration of 200 mg/kg fish/day over a period of 16 days, it did not control the disease, whereas a five day treatment with Chloramphenicol from 15 to 20 December reduced the losses within the following week.

According to Prof. Egusa of Tokyo University (personal communication), disease problems do not exist in Japanese sea water eel farms. Under German conditions one has to expect disease problems even when the eels are cultivated at high salinities, since outbreaks of diseases, likely to be caused by vibriosis, are widely known in the natural eel stocks of the German Bight (Aker, 1971).

4.3 *Other fishes*

Seasonal fluctuations in temperature and salinity obviously restrict the number of fish species that can be cultivated throughout the year under Emden conditions.

Plaice (*Pleuronectes platessa*) kept from March to April could not withstand the low salinity of 4–6 ppt in spring (see Fig. 1). Flounder (*Platichthys flesus*) and turbot (*Scophthalmus maximus*) kept from March to June showed an increase in weight of 10–15% per month when fed with minced fish. Their feed conversion rate was 6:1. All flounder died at temperatures of 28°C, the turbot at 31°C. The upper temperature tolerance for sole (*Solea solea*) kept from March to August was found to be very sharp at 33°C, in accordance with Rumohr (1975). Pike–perch (*Stizostedion lucioperca*) kept from March to August were fed with minced fish and grew well but died at a temperature of 29°C. Freshwater species, such as one-year-old common carp (*Cyprinus carpio*) kept from March to July, sheat fish (*Silurus glanis*) kept from March to July, and grass carp (*Ctenopharyngodon idella*) kept from March to July, as well as Pacific coho salmon (*Oncorhynchus kisutch*) kept

from the middle to end of October did not tolerate salinities higher than 10–12 ppt regardless of whether the fish were exposed to this salinity suddenly or after an adaptation period of several months. All fish which died showed the same symptoms: darkening of the skin and exophthalmia. In addition the sheat fish had skin lesions. On the other hand, the following warmwater fish species—mostly non-indigenous—evidenced no mortality or disease up to January 1976 despite the fluctuating water quality: (*i*) Grey mullet (*Mugil* spp.) 300–800 g in weight, (introduced October 1974), which normally have a more southerly distribution, but were caught in Emden harbour. This species has become more and more abundant in the German Bight in recent years. (*ii*) Rabbit fish (*Siganus concatenata* and *S. oramin*), about 50 g in weight, which originated from the Philippines and were partly bred at the Biological Station of Heligoland (von Westernhagen and Rosenthal, 1975), introduced in August 1975. (*iii*) Sea bass (*Dicentrachus labrax*), about 10 g in weight, introduced September 1975, bred by the Centre Océanologique de Bretagne, Brest. (*iv*) Tilapia (*Tilapia mossambica*) 5 g in weight, introduced September 1975, bred at the Institute for Hydrobiology and Fisheries Science, University of Hamburg.

The siganids were found to be very useful in cleaning basins and screens as they fed on algae and other fouling organisms. However, when kept together with densely stocked eels weighing 20–80 g, the siganids were immediately attacked by the eels and severely hurt if not killed. The sea bass, made available by Dr. Girin of the Brest Institute of CNEXO, fed well on pelleted feed. They increased their body weight within three months from 4 to 9 g with a feed conversion of about 4:1. This is comparable to the results obtained by Alliot *et al.* 1974.

5 Conclusions

Both rainbow trout and eels were found suitable for cultivation under local brackishwater conditions, although the trout could be cultured only during the winter months. The rate of growth of cultured eels (one to two years to attain marketable size) was far greater than that of eels in German inland waters where it requires six to eight years to attain the same size.

The seasonal fluctuations in water temperature and salinity in 1975 were not well tolerated by: plaice, flounder, turbot, sole, pike–perch, common carp, grass carp, sheat fish and coho salmon.

Grey mullet, sea bass, rabbit fish and tilapia could be kept well under the special brackishwater conditions.

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Biological and Economic Aspects of Fish Production in a Closed Warm-Water System

V. Hilge

Abstract

This paper deals with the possibilities of commercial fish farming using a closed warm-water system. Starting with growth curves of mirror carp (*Cyprinus carpio*) reared in an aquaculture system developed at Ahrensburg, Federal Republic of Germany, a model is developed for stocking rates and stocking sequences in relation to the final mean body weight of fish for the given total capacity of a 50 m^3 circuit of 1·5 tons of fish. The highest production, an annual yield of about 8 6 tons of carp, is obtained using a semi-monthly stocking sequence. Three models of a commercial fish farm are presented which differ in heating costs, number of personnel, and number of circuits used for rearing and production of stocking material. The costs of production per kg of carp in the models vary from DM 3·66 to DM 4 29 in comparison with a common cost of DM 3·60 in pond culture.

Aspects biologiques et économiques de la production de poisson en eau chaude dans un système clos

Résumé

Le document traite des possibilités de l'élevage des poissons en eau chaude à des fins commerciales dans un système clos. Après avoir examiné les courbes de croissance de carpes mirroirs (*Cyprinus carpio*) élevées dans un système aquicole mis au point à Ahrensburg (République fédérale d'Allemagne), on a élaboré un modèle pour déterminer des densités et des échéanciers d'empoissonnement compte tenu du poids corporel moyen final du poisson pour une capacité totale d'un circuit de 50 m^3 contenant 1·5 tonnes de poisson. On obtient la plus forte production—un rendement annuel de quelques 8·6 tonnes de carpes—en utilisant un échéancier d'empoissonnement à 15 jours d'intervalle. Le document présente trois modèles de fermes piscicoles à des fins commerciales qui diffèrent par les coûts de chauffage, l'effectif du personnel et le nombre de circuits servant à l'élevage et à la production de matériel de peuplement. Selon ces modèles, le coût de la production d'un kilo de carpes varie de DM 3·66 à DM 4·29 par comparaison avec le coût habituel qui est de DM 3·60 dans les étangs de pisciculture.

Aspectos biológicos y económicos de la producción de peces en un sistema cerrado de aguas cálidas

Extracto

En el documento se examinan las posibilidades de la piscicultura comercial utilizando un sistema cerrado de aguas cálidas. A partir de las curvas de crecimiento de carpa común (*Cyprinus carpio*) cultivada en un sistema de acuicultura ideado en Ahrensburg (República Federal de Alemania) se ha preparado un modelo de índices y ritmos de siembra, en relación con el peso corporal final medio de los peces, para un circuito de 50 m^3, con una capacidad total de 1·5 toneladas de peces. La producción más elevada (un rendimiento anual de 8·6 toneladas de carpas) se obtiene usando un ritmo de siembra semimensual. Se presentan tres modelos de granjas piscícolas comerciales que difieren en los costos de calentamiento, el número de personal y el número de circuitos utilizados para criar y producir el material de siembra. Los costos de producción por kg de carpa en los diversos modelos varían de 3·66 a 4·29 marcos, frente a un costo común de 3·60 marcos en la piscicultura en estanques

1 Introduction

An aquaculture system based on a closed water circuit with water purified by activated sludge has been developed at Ahrensburg in the Federal Republic of Germany. This system has been designed and used exclusively for scientific purposes. In view of the general lack of information on the economics of such systems, it is given trial here as a model for commercial fish production.

2 A 50 m^3 circuit for carp production

The techniques and biology of a 50 m^3 circuit, running on

fresh water and developed at Ahrensburg have been described by Meske (1973). As the mirror carp (*Cyprinus carpio*) is the most important warm-water fish cultured in the Federal Republic of Germany, scientific studies with the system have been concentrated on this species. As data input for the models which will be discussed later was only available for mirror carp, this species was used for the models. Another reason for selecting this species is that induced spawning and controlled breeding permits the production of carp fingerlings throughout the year.

The water volume of the model circuit is 50 m^3: 6 m^3 in the fish tanks and 44 m^3 in the purification unit. The temperature is kept constant at 23°C, the flow rate is 25 m^3/hour, and the maximum carrying capacity is about 1·5 tons of fish. To ensure adequate replication for different experiments, the carp are distributed within a large number of small tanks. Thus, of necessity, the loss of energy with respect to the costs for heating will be higher than it would be in commercially managed circuits. 1% of the total water mass has to be added each day in order to compensate for losses by evaporation and removal of sludge.

3 Growth of carp on different feeds

The carp used in the system are fed on pelleted dry feeds whose quality and quantity influence the growth rate. Fig. 1 demonstrates the difference in growth obtained by feeding two different diets of raw protein (Feed A–47%, Feed B–36%). Temperature, the stocking density and the quantity of food (g food/fish/day) have been kept equal. Four different average weights are shown in this graph (500 g, 1 000 g, 1 500 g, 2 000 g), which indicate different weights for harvesting in the model used (see Table I). For example, it takes about 11% more time to grow a carp from 10 g at stocking weight to a market size of 1 500 g using Feed B for ten months, compared with the use of Feed A for nine months. The influence of the food quantity on growth is demonstrated for another food given at levels of 5% of body weight per day (Feed C_1), and 4% (Feed C_2) (Meske, 1973). In this example, the period of growth required to produce a 1 500 g fish is extended by about 19·5% (12·25 months compared with 10·25 months).

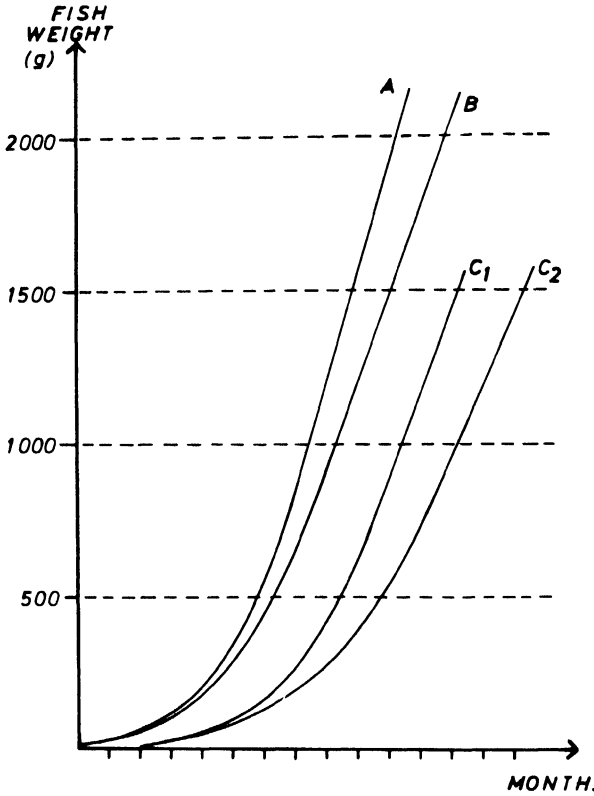


Fig 1. Growth of carp with different feeds (A and B) and at different food rations (C_1 and C_2) in a closed warm-water system. Dotted lines indicate 500 g intervals for final individual mean weights

4 Stocking rates and stocking sequences

Closed circuits have a limited carrying capacity; when the capacity is exceeded, the system may break down. On the 50 m^3 system discussed here, the results obtained during the last few years suggest that its carrying capacity is about 1·5 tons of fish. This indicates a possible relation of total water volume to total fish weight of 30:1 (Meske, 1973). If all the tanks were stocked at the same time with 10 g fish and grown to 2 kg fish, the system would be working far below its carrying capacity most of the time. Using Feed A, the maximum would be reached only every ten months. If, however, the carp were to be raised to sell at a weight of 500 g, the turnover would be reduced to about 5·5 months and the capacity far better utilized.

An even better approach to utilize the capacity to the optimal degree is to stock all tanks in successive charges at

TABLE I

ANNUAL PRODUCTION OF CARP IN A 50 m^3 CLOSED WARM-WATER SYSTEM AT DIFFERENT STOCKING SEQUENCES IN RELATION TO THE FINAL INDIVIDUAL FISH WEIGHT

Feed	*Final weight of individual fish (g)*	*Total production (kg)*		
		System stocked semi–monthly	*System stocked monthly*	*System stocked 1·5 monthly*
A	500	8 474	7 499	6 702
	1 000	7 536	6 768	6 128
	1 500	6 287	5 747	5 307
	2 000	5 558	5 118	4 756
B	500	8 663	7 620	6 753
	1 000	6 813	6 170	5 648
	1 500	5 328	4 950	4 608
	2 000	4 231	3 961	3 756
C_1	500	7 638	6 848	6 206
	1 000	6 552	5 985	5 477
	1 500	5 435	5 044	4 700
C_2	500	6 350	5 787	5 357
	1 000	5 505	5 020	4 715
	1 500	4 663	4 367	4 095

shorter periods. In Table I, the annual production is calculated for Feeds A and B mentioned above for stocking sequences, and consequently also for harvesting, of 0·5, 1 and 1·5 months. For Feed A the total production at a semi-monthly stocking sequence is 35% lower for 2 000 g fish compared with 500 g fish. This relative difference is reduced at longer stocking sequences to 29% at the 1·5 monthly interval. For Feed B, the difference is even more evident. It is 51% at the 0·5 month stocking interval and 44% for the 1·5 month stocking. For 500 g fish in both cases the annual production is reduced by 21% when the stocking sequence is extended from 0·5 to 1·5 months. As Table I indicates, the maximum production is achieved for 500 g fish. Although the carp grow slower when fed with Feed B than Feed A, Feed B provides better annual production for all stocking sequences for 500 g fish.

5 Influence of feeding intensity on carp growth

The influence of the intensity of feeding is shown for Feed C in Table I. The annual production is calculated for a feeding level of 5% body weight/day (Feed C_1) and for a 4% level (Feed C_2). The carp fed with Feed C_1, which receive 20% more food than the fish given Feed C_2, have nearly 20% higher annual production in a semi-monthly stocking sequence. The difference decreases for longer stocking intervals.

6 Influence of costs of feed

As feed costs are the main operating costs when using this system, the differences in income are considerably higher than the differences in the production of fish weight per year as shown in Table I. The total income (less feed costs) has therefore been estimated for different average weights of fish at the time of harvesting for systems using Feeds A and B with three stocking sequences (Table II). It can be seen that, for Feed B at the semi-monthly stocking sequence, the annual production is reduced by 51% from 8 663 kg to 4 231 kg (Table I) and the income by 64% from DM 38 055 to DM 13 708 (Table II) when producing 2 kg fish instead of 500 g fish[1]. The decrease in income is therefore proportionately more rapid than the decrease in production when the size of fish harvested increases and the stocking sequences are prolonged.

[1] US$1·00 = DM2·6

7 Economic models for carp production in closed water circuits

Three economic models for carp production are presented in Table III. All these models are calculated on the basis of 12 circuits, each with 50 m^3 of water, and an annual production of 8 663 kg of 500 g carp per circuit (cf. Table I, Feed B). In Models I and II all 12 circuits are used to produce carp of marketable size. In Model III, one circuit is used for the production of the stocking material. Model I operates on central oil heating; in Models II and III, the energy is derived from heat exchangers connected to industrial cooling water. Thus, the operating costs are reduced by the heating costs (*ie*, for oil) in Models II and III.

In Model III, no costs for the stocking material enters the model and feed costs are reduced, but on the other hand the production and feeding of fry in this model requires the help of three trained persons instead of the two used in Models I and II. In addition, Model III has a lower production because one less circuit is available for the production of marketable carp.

The calculations in Table III are based on the following data:

(*a*) carp are sold at DM 6/kg
(*b*) price of food: DM 1·15/kg
(*c*) conversion rate (kg food/kg weight gain): 2
(*d*) salary per person/year: DM 26 000
(*e*) oil for heating: DM 0·25/l
(*f*) at a flow rate of 25 m^3/hour the decrease in temperature is 0·5°C; thus, 600 m^3/day have to be heated through 0·5°C
(*g*) 60 l of oil (based on heating efficiency of 0·5) are needed for heating each day, and heating costs are DM 5 475/year
(*h*) electric power: 100 kWh/day at DM 0·12/kWh and costs per year of DM 4 380
(*i*) 500 l of water must be added per day (i.e., 1 percent loss per day) to a system at a price of DM 2/m^3; annual costs of water is therefore DM 365
(*k*) 18 000 carp fingerlings of 10 g each at DM 0·15/fish, costs per year DM 2 700 (no mortality was considered in the models)
(*l*) capital investment: DM 1 200 000
(*m*) annual production: 8 663 kg of carp per circuit
(*n*) total costs for keeping spawners and for production and feeding of fry are estimated at DM 18 000 (for Model III only).

All three models require an estimated capital investment of DM 1 200 000. On the basis of DM 6/kg of carp, Models I and II produce carp valued at DM 623 740, while Model

TABLE II
INCOME (AFTER REDUCTION OF FEED COSTS) FROM ANNUAL PRODUCTION OF CARP IN A CLOSED WARM-WATER SYSTEM IN RELATION TO THE SEQUENCE OF STOCKING AND FINAL WEIGHT OF INDIVIDUAL FISH (IN DM)

Feed	*Final weight of individual fish* (*g*)	*Income (DM)*		
		System stocked semi-monthly	*System stocked monthly*	*System stocked 1·5 monthly*
	500	30 676	27 147	24 262
	1 000	29 165	26 192	23 715
	1 500	23 136	21 149	—[a]
	2 000	19 564	18 015	—
	500	38 053	28 194	24 986
	1 000	23 928	21 718	19 881
	1 500	17 955	16 682	—
	2 000	13 708	12 834	—

[a] Indicates values not calculated

III production is worth 8·3% less. In Model I, the operating costs are equivalent to more than 70% of the value of the fish produced, and feed costs are about 57% of the operating costs. In Model II, the operating costs are reduced by DM 65 700 for heating. This results in a reduction of the operating costs per kg of fish by nearly 15%, *ie*, from DM 4·29/kg to DM 3·66/kg. The fingerling production within the system does not compensate for the costs of buying the stocking material; one more person is employed and additional costs for production and feeding of fry lead to an increase of operating costs of DM 3·90/kg of marketable fish.

TABLE III
ECONOMICS OF CARP CULTURE IN THREE CLOSED, WARM—WATER MODEL SYSTEMS USING FEED B, A SEMI-MONTHLY STOCKING SEQUENCE AND TOTAL ANNUAL PRODUCTION OF 8 663 kg FISH (AVERAGE INDIVIDUAL WEIGHT 500 g)

		DM
Model I		
Capital investment		1 200 000
Operating costs		
Feed	239 100	
Personnel	52 000	
Oil (for heating)	65 700	
Water	4 380	
Electricity	52 560	
Stocking material	32 400	
Total		446 140
Income		623 740
Profit minus depreciation (10%)		57 600
Operating costs per kg of fish		4·29
Model II		
Capital investment		1 200 000
Operating costs		380 440
Income		623 740
Profit minus depreciation (10%)		123 300
Operating costs per kg of fish		3·66
Model III		
Capital investment		1 200 000
Operating costs		
Feed	219 180	
Personnel	78 000	
Electricity	52 560	
Water	4 380	
Others	18 000	
Total		372 100
Income		571 760
Profit minus depreciation (10%)		79 600
Operating costs per kg of fish		3·90

8 Discussion

This paper provides a model for an economic approach to commercial fish farming in closed-water circuits. The biological data as well as the operating costs have been derived from an experimental circuit used for scientific studies. Operating costs, especially those related to technical design, must be considered as preliminary and may change for commercial farming. Circuits larger than 50 m^3 will probably be more economical and reduce investment and operating costs. A lesser number of larger tanks compared with the large number of experimental tanks will allow better isolation of stocks and should reduce the heating costs of Model I.

Feed costs are relatively high because trout pellets have been fed rather than complete carp feeds, which are available for DM 0·9/kg. Therefore, food costs, which represent more than 50% of the total operating costs, could be reduced considerably. Furthermore, a search for cheaper feeds with lower conversion rates is still incomplete. Fish feeds with lower conversion rates are of special importance. With their use one can expect less organic load in the system and thus higher carrying capacity within a circuit, with a consequent better economic return.

Even if the production of stocking material increases production costs, it must be recommended as a means of preventing diseases and parasites from entering the system.

The models given for carp production lead to an estimate of operating costs of DM 3·66/kg of fish; this is in the same order of magnitude as for pond farming of carp in Western Germany, for which production costs of DM 3·60/kg of fish are common.

Carp is, of course, one of the cheapest fish farmed in Germany and other countries. Other fish like trout (*Salmo*) or eel (*Anguilla*) have a much greater market value. For these species, however, only part of the data necessary for a model are available. The model presented, however, permits adjustments to other biological or technical parameters.

9 Reference

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A Technical and Economic Review of the Use of Reconditioned Water in Aquaculture

R. D. Mayo

Abstract
Water reconditioning technology has been applied to a number of major aquaculture projects in North America and can have significant impact on the economic success of future projects. A convention for definitions and analytic techniques is proposed and processes described. Literature on the technology is reviewed and major applications, economic impacts, and research needs are defined. The best prospects for application are ocean ranching, fingerling production and the expansion of existing hatcheries.

Examen technique et économique de l'emploi de l'eau recyclée en aquaculture
Résumé
Les techniques d'utilisation des eaux recyclées ont éte appliquées à plusieurs grands projets d'aquaculture en Amérique du Nord et peuvent avoir une influence notable sur la réussite économique de futurs projets. Le document soumet une convention relative aux définitions et aux techniques analytiques et décrit divers procédés. La littérature technique sur la question est passée en revue et l'on définit les principales applications, les effets économiques et les besoins en matière de recherche. Les meilleures perspectives d'application sont offertes par l'élevage océanique, la production d'alevins et l'expansion des centres d'alevinage existants.

Examen técnico y económico del empleo de agua reacondicionada en acuicultura
Extracto
En varios proyectos importantes de acuicultura realizados en América del Norte se ha empleado una tecnologia de reacondicionamiento del agua que puede tener importantes repercusiones para el éxito económico de proyectos futuros. Se propone un acuerdo sobre definicions y técnicas de análisis y se describen los diversos procesos. Se examina la bibliografía sobre esta tecnologia y se definen sus principales aplicaciones, sus repercusiones económicas y las investigaciones que aún son necesarias. Los campos que mejores perspectivas ofrecen para la aplicación de esa técnica son "ocean ranching", la producción de jaramugos y la expansión de las piscifactorias existentes.

1 General

1.1 *Purpose*

The understanding of water-reconditioning technology and

its application to aquaculture can have significant impact on the economic viability of many of the aquaculture projects now in various stages of development. This technology has developed at an accelerating rate over the last 15 years. Major applications suggest that it is a useful tool to be used in expanded aquaculture production.

Successful systems are not the rule, however, and much is still to be learned. This paper is presented as a review of this technology, to provide a base from which the learning process can be accelerated and to help planners avoid repetition of previous mistakes.

1.2 *Geographic focus*

There is emphasis here on the type of complex systems used in a number of major applications in North America. Such a geographic focus reflects the author's experience and the lack of literature suggesting other large-scale applications.

1.3 *Species focus*

Most major aquaculture reconditioning units are used for finfish culture, primarily that of salmonids. Thus, this discussion is focused on that area. Other applications should not be ignored, however, because reconditioning appears to be especially appropriate to lobster and prawn culture (Kramer, Chin and Mayo, Inc, 1974).

1.4 *Natural systems*

Emphasis in this discussion is on sophisticated systems constructed by man in conjunction with major aquaculture facilities (as typified by large, salmon-smolt propagation hatcheries or commercial trout farms). This responds to the magnitude of expenditures programmed for future systems. However, it is important that we do not forget that many natural water-reconditioning systems now exist. These are typified by Asian carp ponds, catfish farms in the USA, and fishpens in natural bodies of water throughout the world. A full understanding of these systems may offer the best potential for cost reduction.

The definitions and analysis presented here are appropriate to this understanding because, in the longer view, natural systems and sophisticated systems differ little in function or results.

1.5 *Objectives*

This paper has these objectives: (*a*) provide a common base for the discussion of water reconditioning in aquaculture through a series of definitions; (*b*) describe the range of processes which may be involved in water reconditioning; (*c*) describe why reconditioning is used in aquaculture; (*d*) review the literature; (*e*) summarize major applications; (*f*) provide some economic information; (*g*) suggest areas of research.

1.6 *An historical and economic perspective*

In North America, development of reconditioning systems was given impetus by US Federal programmes to mitigate the loss of natural Pacific salmon propagation in the Columbia River basin that resulted from construction of hydro-electric dams. Research began with empirical analysis in the early sixties. In 1967, systems were installed at the Dworshak Steelhead Hatchery on the Snake River (a tributary to the Columbia River in the State of Idaho) where sea-run rainbow trout (*Salmo gairdneri*) were reared. Studies of the Dworshak systems continued and, although initial success was somewhat limited, sufficient optimism was generated regarding the possibility for refinement that improved systems were installed at other Federal hatcheries on the Columbia River and elsewhere. Today, a number of large, intensive-culture hatcheries with reconditioning systems are in various stages of design and construction. Capital expenditure for reconditioning systems already constructed (see Table I) is of the order of US$ 10 million.

2 Definition of systems and processes

This section is concerned with proposing definitions and analysis conventions, and with describing with a minimum of detail some of the processes. This material is based primarily upon referenced work by Liao, Mayo and Kramer, Chin and Mayo, Inc. Thus, specific references are sometimes excluded in this section as attribution is properly to several documents.

2.1 *Fish rearing systems*

As a basis for discussing water reconditioning systems, it is useful first to visualize the entire fish rearing system in its several forms. For example, there is the simple flow-through system of Fig. 1 which is, primarily, a rearing unit.

However, it is often necessary to modify the character of the water supply prior to use in the fish-rearing unit through some form of pre-treatment. On occasion, it also is necessary to provide post-treatment to water from a rearing unit before it discharges into the receiving water. This is illustrated in Fig. 2.

The quantity of water required from the supply for the systems described in Figs. 1 and 2 is primarily a function of the water quality, the oxygen requirements in the rearing units, and the tolerance of the fish to their own metabolic products. Other factors of occasional importance are hydraulic requirements, incidental pollution, and temperature or acidity changes in the rearing units.

When the water supply is inadequate, or when pre- and post-treatment costs are high, the fish culturist often must resort to some form of water reconditioning to allow re-use of the available supply, as illustrated in Fig. 3.

2.2 *Water treatment processes—general*

2.2.1 *General process definition.* Figs. 2 and 3 describe how three water treatment systems may be part of fish rearing systems. These treatment systems may consist of one or more treatment processes, each of which can be described as a process which changes the character of the water that passes through it in one or more ways. A simple process, for example, would be one where the water is simply heated. A more complex process would be one in which oxygen is added and ammonia is removed in a single operation. While

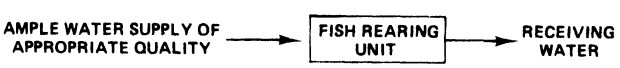


Fig 1. Simple flow-through (single-pass) system

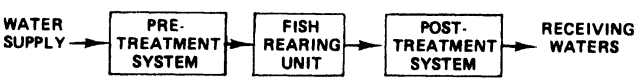


Fig 2. Single-pass system with pre- and post-treatment

Table 1. Major reconditioning systems

	DWORSHAK NO. 1 IDAHO	DWORSHAK NO. 2 IDAHO	DWORSHAK NO. 3 IDAHO	SPRING CREEK WASHINGTON	COLEMAN CALIFORNIA	LAHONTAN NEVADA
SYSTEM & LOCATION	Dworshak National Fish Hatchery Orofino, Idaho	Dworshak National Fish Hatchery Orofino, Idaho	Dworshak National Fish Hatchery Orofino, Idaho	Spring Creek National Fish Hatchery Washington	Coleman National Fish Hatchery Anderson, California	Lahontan National Fish Hatchery Gardenerville, Nevada
STATUS SEP. 1975	In Service	In Service	In Service	In Service	In Service Dec. 15 – June 15	In Service
MAJOR CONNECTED REARING UNITS	25-600 gpm circulating raceways 75' x 17' x 3'	25 600 gpm circulating raceways 75' x 17' x 3'	34-600 gpm circulating raceways 75' x 17' x 3'	44 700 gpm circulating raceways 17' x 75' x 2 5'	30 420 gpm rectangular raceways 8' x 80' x 2'	36 400 gpm rectangular raceways 10' x 95' x 2'
MAX. DESIGN FISH LOAD/REARING UNIT	7650 lb/unit (raceway)	7650 lb/unit	7630 lb/unit	4300 lb/unit	1260 lb/unit	1280 lb/unit
RECONDITIONING TREATMENT	1 Crushed oyster shell filtration for pH control @ 1 gpm/sq ft 2 Rock biofiltration 3 ft deep for nitrification @ 1 gpm/sq ft 3 Biofilter is a downflow type 4. Aeration – Aspirator 5 Filters backwashed to prevent clogging – once every 4 days R = 0 90	1 Upflow biofilter with Norton Rings 2 Settling basin for solids removal 3 Aeration – Aspirator 4 Four feet of Norton Rings 27 sq ft/cu ft 4 beds 25' x 75' x 4' R = 0 90	1 Settling basin for solids removal 2 Upflow biofilters with Norton Rings 4 Four feet of Norton Rings 6 beds 25' x 75' x 4' R = 0 90	1 Crushed oyster shell filtration (4" –start at 1 ft) for pH control @ 1 gpm/sq ft 2 Rock biofiltration 4 ft deep for nitrification @ 1 gpm/sq ft 3 Biofilter is a downflow type 4 Aeration – Aspirator 5 Filters backwashed to prevent clogging – twice a week R = 0 90	1 Oyster shell filtration for pH control @ 1 gpm/sq ft (2 filter bays) 2 Rock biofiltration (2 filter bays) for nitrification @ 1 gpm/ sq ft 3 Two filter bays upflow with 3½ inch Koch Rings 4' deep 4 Two filter bays empty 5 Aeration – Aspirator R = 0 90	1 Upflow biofilter with Koch Rings 2 Settling basin area below biofilter 3 Aeration Vortair Turbine Aerators (Infilco) R = 0 90
PRETREATMENT	1 Electric grid 2 Sand filtration to eliminate 10 micron and larger particles 3 U V sterilization 4 Heating and chilling to maintain rearing unit temp in 50 58°F range	1 Electric grid 2 Sand filtration to eliminate 10 micron and larger particles 3 U V sterilization 4 Heating and chilling to maintain rearing unit temp in 50 58°F range	1 Electric grid 2 Sand filtration to eliminate 10 micron and larger particles 3 U V sterilization 4 Heating and chilling to maintain rearing unit temp in 50 58°F range	Spring Water No Treatment	Heat exchanger	Well Aeration
POST TREATMENT	None Discharge prior to biofilter (settling basin by 1977)	1 Discharge after biofilter and aeration treatment and solids settling basin 2 Collected solids treated in aerobic digester 3 Solids to drying bed 4 Supernatants to river	1 Discharge after biofilter and aeration treatment and solids settling basin 2 Collected solids treated in aerobic digester 3 Solids to drying beds 4 Supernatant to river.	Effluent treatment consists of a settling and stabilizing lagoon equivalent to 18 hour detention The lagoon is divided into two portions by a concrete dam type dividing wall Basin One has 3½ 4 hour detention	None Discharge prior to biofilter	
OPERATING HISTORY	1 Ichthyophthirius (Ich) has been a problem each year since 1971 2 Treatment for "Ich" tends to introduce secondary Epizootics i e Salmincola (Blood Fluke) due to the switch to raw water 3 Problems with oyster shell rock biofilter clogging and need for frequent backwash	1 Low level of "Ich" but controlled by drawing pond down Possible control of Ich due to settling basin No chemical treatment was required in 1974 2 Power failure caused the raw water to flow–some loss due to smothering However, a bigger problem was the high nitrites from the undrained filters when power was restored 3 Normal operating pH was lower than rock and oyster shell system and ammonias were higher	1 "Ich" was present, however, not a major problem 2 Nitrite build up was noticed, however, mortality was less than 10% even with nitrite and "Ich" combined 3 Treatment with Formaldehyde was done during the threat of an Epizootic	1 Redmouth is a re occurring problem 2 Gill bacteria occurred and treatment with chemicals (Roccal, Steatex) was done 3 Fines from automatic fish feeder didn't help the condition (21% dust originally) Reduced dusting by slowing feed Now at 2½% 4 Chinook and Coho were reared in the system with 11% mortality 5 Ammonias tended to follow feed levels Over feeding caused high ammonias to occur 6 Dust from feed causes problems in the rock and oyster shell biofilters making backwash more difficult to accomplish 7 Oyster shell settle into rock	1 1972–Only the two rock and oyster shell filter bays were in use 2 Maximum fish loading was 4500 lbs with 1600 gpm system flow 3 1973 74–Four filter bays were in operation– Two rock and oyster shell Two Koch Rings (3½") 4 Downflow rock and oyster shell @ 1 gpm/sq ft 5 Upflow Koch Rings @ 2 gpm/sq ft 6 Maximum fish load was 7500 lbs fish 7 Fifteen raceways used in 1973 Twenty raceways used in 1974 8 Operating pH 8 2 @ 60°F total pond NH_4 N 0 42 ppm Nitrite N–0.025 ppm 9 Ammonia Levels at Peak Fish Loading Upflow Koch Ring: In 62, Out .55 Downflow Rock & Oyster Shell: In 62, Out .04 10 Problems-- Low ammonia removal in upflow system No standby power–use of battle creek water caused disease problems Heat exchanger capacity insufficient	1 System operated okay until Dec 10, 1973 2 No sludge removal results in ammonification 3 Insufficient number of filter bays for present facilities 4 Reuse pumps not pumping 5000 gpm but only 3900 gpm maximum 5 Sludge removal is accomplished by dewatering the filter bay and hosing it out

Table 1 (continued)

	CAPILANO BRITISH COL.	CRYSTAL LAKE ALASKA	MAD RIVER CALIFORNIA	FIRE LAKE ALASKA	SEA POOL NOVA SCOTIA	WARM SPRINGS OREGON
SYSTEM & LOCATION	Capilano Fish Hatchery British Columbia, Canada	Crystal Lake Fish Hatchery Petersburg, Alaska	Mad River Hatchery Blue Lake, California	Fire Lake State Hatchery Anchorage, Alaska	Sea Pool Clam Bay Nova Scotia, Canada	Warm Springs National Fish Hatchery Warm Springs, Oregon
STATUS SEP. 1975	Operational – optional	In Service	In Service	In Service	Closed Down – after 1973–1974	Partially Constructed
MAJOR CONNECTED REARING UNITS	10-600 gpm circulating raceways 17' x 75' x 4-4½'	10 600 gpm circulating raceways 17' x 76' x 4'	5-1000 gpm rectangular raceways 20' x 300' x 4'	Several circular and circulating raceways 1500 gpm flow	Reuse– 2–500' long raceways 20–25' circular 3 5'-4' deep 6–50' circular 3 5'-4' deep 35' circular gravel and plastic Total est flow 10,000 gpm	30 750 gpm circulating raceways 17' x 75' x 3'
MAX. DESIGN FISH LOAD/REARING UNIT	2500 lb/unit					
RECONDITIONING TREATMENT	1 Downflow rock filter After filter, backwash wastewater to sewer system (filter used only for solids removal) 2 No aeration R = 0 90	1 Poly bead upflow filter 5–20' x 50' x 2' @ 2 gpm/sq ft 2 Up to 20 passes 3 Aeration 4 Oyster shell buffers R = 0 95	1 Rock and oyster shell 2 Settling basin for discharge and backwash water R = 0 90	Originally rock and oyster shell recently converted one to downflow with styrofoam balls 4 beds U V sterilization R = 0 90	1 Rock and oyster shell biofilters 4 reuse systems R = 0 80 to 0 95	Upflow plastic media filter R = 0 90
PRETREATMENT	River – none	1 Sand filters 25 microns 2 U V sterilization 3 Aerators 4 Heating	1 Well water 2 Sand filtration for removal of particles > 20 microns 3 U V	1 Sand filtration 2 Intake depth selection for temp control 3 U V sterilization	Pre settling 600' long, 200' wide, 10 15' deep salt water system	None for Hatchery Building only 1 Electric grid 2 Heating and chilling 3 Sand filtration 4 U V sterilization
POST TREATMENT	Yes	Treatment provided 2 small 20' x 30' detention ponds	Yes, settling of discharge and backwash water	None	None	Cleaning waste to presettling Normally none
OPERATING HISTORY	1970 1972 Never used biofilter - but designed to filter solids 1975 Fish kill due to chlorine from Vancouver water supply penstock	1974 – 1975 Successful winter operation last year Nitrogen supersaturation	Frunculosis	1 Gill disease continuing problem (Diqvat and Roccal used to control) 2 Uncontrollable problem with Coho shortly after start feeding 3 Chinook (King) Salmon had coagulated yolk in fry and early fingerling– causing high mortalities	Start up 1969 1 All diseases present 2 High nitrite main killing factor 3 Bed filter plugged - backwashed – 1 3 days	None

Table 1 (continued)

	RATHBUN IOWA	WARM SPRINGS CALIFORNIA	BAYFIELD WISCONSIN	ALSEA OREGON	KOOSKIA IDAHO
SYSTEM & LOCATION	Rathbun Fish Hatchery Rathbun, Iowa	Warm Springs California	Bayfield Fish Hatchery Bayfield, Wisconsin	Alsea Steelhead Hatchery Oregon	Kooskia, Idaho
STATUS SEP. 1975	Partially built—under construction	Under Construction	In Service	In Service	Reuse Jan to Nov 1— then back to creek water
MAJOR CONNECTED REARING UNITS	20—940 gpm circulating ponds 48' x 48' x 3.5' (8-now – 12-next year)	8-750 gpm rectangular raceways 8' x 80' x 4'	14-550 gpm rectangular raceways 8' x 76' x 3'	20-500 gpm rectangular raceways 10' x 100' x 3'	6-600 gpm circulating ponds 17' x 75' x 2½'
MAX. DESIGN FISH LOAD/REARING UNIT		10,000 lb/unit	3600 lb/unit	7000 lb/unit	4000 lb/unit
RECONDITIONING TREATMENT	Multiple pass system w/aeration R = 0 50	Aeration—2 pass system or ammonia limiting R = 0 40 to 0 70	1 Sweco unit—400 mesh 2. Re-aeration R = 0 50	Simple re aeration with out-of-service raceways used for settling R = 0 50	1 To hold temp down during summer 2 Expanded shale upflow w/backwash ¾-½" shale 3. Four feet of settling bay w/scraper 4 Three surface aerators on styro foam floats R = 0 90
PRETREATMENT	1 Pre screen 2 Aeration 3 Electric grid 4 Sand filtration 5 U V sterilization 6. Heating and chilling	1 Aeration 2 Iron settling if needed 3 Sand filtration 4 U.V sterilization 5 Heating and chilling	Well—no treatment Lake trout on Creek—Baker Filter 10 micron and greater		Well water—58° 400 gpm Chill to 52°—54°
POST TREATMENT	Pollution control pond 2—2 acre ponds 4' deep 2-hour detention each @ 13 cfs	Pollution control pond aerated section followed by settling	Waste Pollution Control 1 Surface Aerator 2 Sweco waste and normal flow		1 Sludge to settling pond 150' x 1/8 mile x 3-4' deep 2 After biofilter and aerator
OPERATING HISTORY	Under Construction Special Note This facility for intensive culture of catfish All others for salmonids	None	7 months operating (partial)—just underway		One Year 1 Ammonia removal fair 2 Used dilution to control ammonia 3 "Ich" not found in reuse system

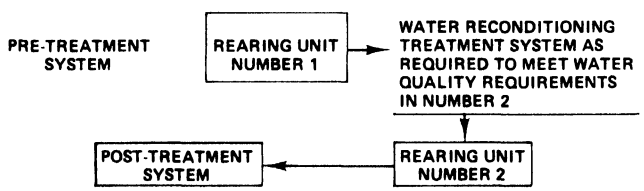


Fig 3. A system which re-uses water in its fish-rearing units

an individual process can be complex in the number of changes it makes in the character of the water, it can be simple in its configuration. For instance, a process whereby the flow is re-used after being directed through a large lagoon (physically a simple facility) can be expected to change the character of the water in many ways

Individual processes which may be part of the three treatment systems include:

2.2.2 *Pre-treatment processes.*

Sedimentation	Aeration
Screening	De-gassing (nitrogen, CO_2 removal)
Shocking (to kill aquatic life)	Heating
Filtration	Cooling
Sterilization	pH control

2.2.3 *Reconditioning treatment processes.*

Sedimentation	pH control
Mechanical filtration	Heating
Biological filtration	Cooling
Aeration	Sterilization
Extended aeration	De-gassing
Activated sludge	Ion exchange

2.2.4 *Post-treatment processes.* Except in the case of a

complete re-use system (such as non-overflow ponds or many aquarium tanks), there is a continuous discharge of water from fish rearing systems. This water often will require some form of (post) treatment after use and prior to discharge into receiving water. Typical post-treatment processes include:

Aeration	Digestion or equivalent (such as, de-watering and incineration)
Sedimentation	
Filtration	
Disinfection	Coagulation
Activated sludge	Absorption (taste or odour removal by activated carbon)
Lagooning	

2.3 *Reconditioning treatment processes*

Systems used for reconditioning water are occasionally a single process, such as aeration. More typically, they are a combination of processes. To understand the system it is necessary to understand the individual processes. This section discusses some of the more important processes.

2.3.1 *Aeration.* Aeration can serve various treatment needs including heating, cooling, oxygen input, and release of gases, such as CO_2, NH_3 and atmospheric nitrogen.

Several aeration methods exist; the choice of which method to use is based upon economics, tempered by concern for fish culture needs. The effectiveness of various aeration devices is shown in Fig. 4 (Liao and Mayo, 1972).

The several factors basic to all aeration methods are: (*a*) In the range of oxygen levels above 60% of saturation, aeration becomes increasingly costly. Aeration to over 95% seldom can be justified. (*b*) Excessive aeration tends to modify water temperatures to a point matching air temperatures. This may or may not be considered desirable. (*c*) Aeration methods which tend to expose water surfaces to air at minimum pressures also tend to release gases in excess of saturation. Bubbles under pressure tend to entrain gases to levels in excess of saturation. (*d*) As water becomes increasingly contaminated with organic solids, as may occur in re-use systems, its oxygen absorption capacity is reduced. This effect is magnified in some aeration devices in which slimes form that reduce the turbulent actions which aid aeration.

2.3.2 *Mechanical filtration.* This term as used here refers to a process where solids are 'mechanically' filtered from the water by media such as sand, finely broken oyster shell, diatomaceous earth, or graded media (reverse bed). Other changes, such as pH modification or biological filtration, may take place in the water supply during mechanical filtration.

The need to be cleaned periodically by backwashing or some form of agitation is a feature of any mechanical filtration process. In hatchery systems, this sometimes is made difficult by the 'matting'.

Most mechanical filtration systems can reduce organic (settleable and colloidal) and inorganic solids significantly, but little reduction in dissolved materials will be realized.

It has been demonstrated in a 10-pass reconditioning system for salmonids that sand filters (No. 30 sand) operating at 5 gal/min/ft^2 (3·3 l/sec/m^2) have the capability of removing 70–90% of the suspended solids in water leaving a raceway, as well as 15% of the ammonia (range 2–35%) (Kramer, Chin and Mayo, Inc., 1973).

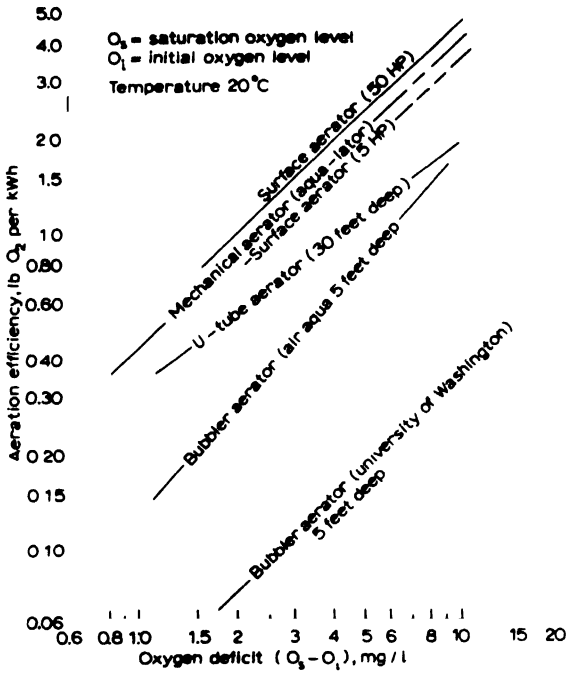


Fig 4 Aeration efficiencies of various aerators

2.3.3 *Sedimentation.* Sedimentation serves the same function as mechanical filtration, *ie*, removal of solids. However, there are important differences.

In filters, particle size is the major determinant of removal, while in sedimentation the 'size-density' factor controls. Thus, organic solids, especially those of small size or of colloidal nature, may not be removed by sedimentation.

Solids can be removed on a continuous basis in sedimentation; thus no backwashing process is required.

Sedimentation can be accomplished by detention, such as in open clarifiers, channels and lagoons. A 1 h retention clarifier used for raceway effluent typical of a salmonid hatchery with a 10-pass system, is reported to remove 70% of the solids and 20% of the ammonia (Kramer, Chin and Mayo, Inc., 1972).

2.3.4 *Centrifugal concentrators.* A centrifugal wastewater concentrator, originally designed for stormwater treatment, has been tested for post-treatment in fish hatcheries. It is apparent that this sytem also has application in reconditioning treatment systems. Kramer, Chin and Mayo, Inc. (1974) tested such a unit in co-operation with several private and governmental agencies and found it to be relatively effective in removing suspended solids (61%) and nitrates (48%). Reported ammonia removal was approximately 25%, though some difficulty was encountered in the measurement. This device also provided an effective method of increasing dissolved oxygen. Operation of this unit required about 10 ft (3 m) of hydraulic head.

2.3.5 *Biological filtration.* Biological filtration is a process which changes water quality primarily by changing substances in the water to other forms that are either less noxious than the original or can be more easily removed by other processes.

In fish rearing and water-reconditioning systems, primary concern is with nitrifying processes that reduce levels of certain metabolic by-products. The paths whereby these

by-products (NH_3, NO_3, and/or PO_4) are reduced or changed in a biological filter are illustrated by the following equations:

$$2\,NH_3 + 3{\cdot}5\,O_2 \xrightarrow{\text{Nitrosomonas}} 2\,NO_2 + 3\,H_2O$$

$$NO_2 + O_2 \xrightarrow{\text{Nitrosomonas}} NO_3$$

$$NO_3 + NO_3 + CH_2O \xrightarrow{\text{Denitrification}} N_2, N_2O$$

$$NH_3 + CH_2O + O_2\ \text{cel} \xrightarrow{\text{synthesis}} \text{BIO-MASS}\ (C_2H_6NO_2)$$

reversible in absence of nutrient

(Remaining NO_3 and NH_3 will remain as NO_3 or will be combined as shown below or into a salt inorganic)

$$NH_3 + H_2O + PO_4 + CO_2 + \text{light} \xrightarrow{\text{photosynthesis}} \text{organic} + O_2$$
$$NO_3$$

$$NH_3 + Mg + PO_4 \longrightarrow Mg(NH_4)PO_4 \quad \text{(insoluble)}$$

$$N\ (\text{heavy metal ion}) + n\,NH_4^+ \longrightarrow M(NH_4)n^{++} \quad \text{(insoluble ion)}$$

Of special significance in salmonid culture is the first equation where nitrite (NO_2^-) is formed. Under a steady-state situation, NO_2^- is converted to NO_3^-. However, because the *Nitrosomonas* bacteria must start action before the *Nitrobacter*, there is a period during unit start-up when nitrite will be predominant. If the NO_2^--N level exceeds 0·2 mg/l, toxic conditions will exist for salmonids. Fig. 5 illustrates this situation in dimensionless terms (Williams, 1971; Smith, 1971).

The bacteria, which serve as the basis for the nitrification processes, are thought to fix themselves to the media used in the filter. These media can be gravel, sand, wood slats, plastic forms or almost any material that provides a relatively stable surface. The choice, where rationally made, depends upon the loading and the filter-cleaning system provided.

The effectiveness of various biological filters in the removal of ammonia varies greatly with both the loading and the system. Plastic media systems, with the hydraulic loadings necessary (1–5 gal/min/ft² or 0·65–3·3 l/sec/m²) in intensive-culture systems for salmonids, reduce ammonia in the following amounts in a single pass through the filter (Kramer, Chin and Mayo, Inc., 1972).

Retention time (min)	*Reduction (%)*
12	20
30	48
38	60

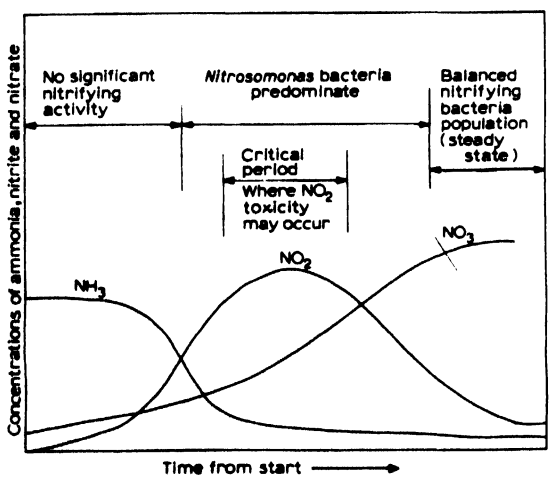


Fig 5. Nitrite development during the system activation

2.3.6 *Nitrifying micro-colonies.* Similar in function to the nitrifying biological filters described above would be the nitrifying micro-colonies reported tentatively by Meade (1975). He has suggested that systems can be devised with no media base for nitrifying and that it would be possible to maintain the necessary nitrifying biomass within a fish-culture system in the form of free-floating micro-colonies. This concept has not been demonstrated on a major scale, but it does suggest an appropriate direction for research.

2.3.7 *Ion exchange.* Various chemical means for removing ammonia from fish rearing systems have been evaluated. One of these, ion exchange, has shown special promise with use of the naturally occurring substance, clinoptilolite.

Its use involves passing water through a clinoptilolite filter bed to remove ammonia. A brine solution is then used for the regeneration of the filter bed. Kramer, Chin and Mayo, Inc. (1973) reported 98% removal in such a system operating at a hydraulic loading of 8 gal/min/ft² (5·4 l/sec/m²) through a depth of 6 ft (1·8 m).

2.3.8 *Temperature control.* Temperature modification is an often-used reconditioning process. Temperature control can be accomplished in many ways, but the quantitative requirements are heavily influenced by conditions in the remainder of the fish-rearing system. For example, excessive aeration can lead to excessive heating and cooling requirements, or open raceways can result in a significant heat gain or loss.

2.3.9 *pH control.* The use of water for fish rearing and the use of some bio-reconditioning systems typically can change the pH of the water supply to some value unsuited for further fish rearing. This is generally related to the effect of pH on the ionic form of ammonia (Burrows, 1964). To maintain the pH at a suitable level, chemical buffering sometimes is used in hatchery systems. Buffering systems for hatcheries include: crushed oyster shell filters; limestone filters; and the addition of buffering chemicals, such as soda, ash or lime.

Kramer, Chin and Mayo, Inc. (1972) studied a number of buffering approaches suitable to a major salmonid hatchery. All were determined to be technically acceptable and criteria were developed.

The manipulation of natural pH is suggested as a way to reduce ammonia toxicity by several authors, including, Sousa, Meade and Wolke (1974).

2.4 *Reconditioning treatment systems*

2.4.1 *General definitions.* Reconditioning treatment systems are defined here as three different types. To a degree, this division is arbitrary, but it does provide a useful basis for understanding function and reliability.

Simple Reconditioning System: This is one where the

processes used add something only to water leaving the rearing units, so as to allow its re-use in other rearing units. Typically, such a process would be aeration and the number of times water may be re-used is one to five times. One such system is illustrated in Fig. 3.

Fig. 6 illustrates another such simple reconditioning system. (Q is water flow rate with arbitrary, dimensionable values shown.) Based upon the values shown this system would be defined as a three-pass (or 67% re-use) system.

Complex (Open) Reconditioning System: With this type, water flows into the system continuously and normally is subjected to two or more processes that extend its use from 5 to 50 times by reducing concentrations of certain metabolic by-products. Fig. 7 provides an example operating as a five-pass (or 80% re-use) system.

Complex (Closed) Reconditioning System: This is similar to the 'open' system except, by the definition proposed here, water use is extended from 50 (50-pass, 98% re-use) to an infinite number of times (100% re-use). An example might be a lightly loaded aquarium with a bottom sand filter (acting as a biological filter), where the operating objective is to keep a stable population of fish alive (see Fig. 8).

2.4.2 *General system analysis.* To understand these systems, it is useful to know their mathematical analysis. An analysis approach was developed by Liao and Mayo (1972 and 1974) and is summarized here.

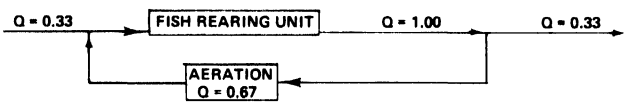


Fig 6. An example of a simple (recirculation) reconditioning system

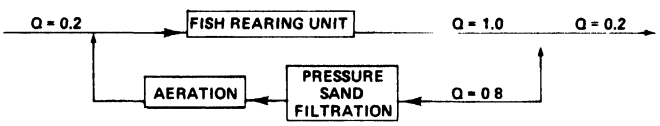


Fig 7. An example of a complex (open) reconditioning system

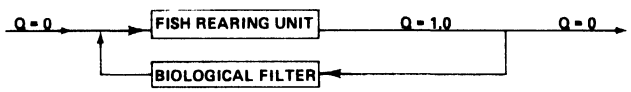


Fig 8. An example of a complex (closed) reconditioning system

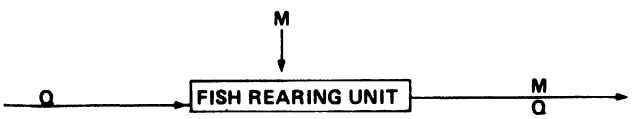


Fig 9. Metabolite level of single-pass system

(*a*) Given the following system (Fig. 9) of water use for fish rearing, the concentrations of metabolic by-product at the rearing unit outlet is M/Q, with M being the input of a metabolic by-product and Q being the flow.

(*b*) Given a reconditioning system where the treatment process removes (or modifies) the metabolic by-products, the concentration of metabolic by-products at the rearing unit outlet is $C \times M/Q$,

where $C = \dfrac{1}{1 - R + RE}$

and R = Portion of raceway water supply being re-used.

and E = the efficiency of the treatment unit in removing or modifying a given metabolic by-product.

2.4.3 *Analysis examples.* Simplified examples of the analysis of the four systems just described are provided in Table II.

3 Why reconditioning systems are used

3.1 *General*

Previous sections have attempted to provide a basis for understanding reconditioning systems, and it is appropriate to understand why they are used in aquaculture. A water-reconditioning treatment system is indicated where: (*a*) the available water supply quantity is inadequate for the proposed fish culture programme; or (*b*) the most economical combination of treatment processes needed to meet the water quality requirements of the proposed fish culture programme is one that includes reconditioning.

3.2 *Quantity criteria*

Where the available water supply quantity is inadequate to carry the required oxygen to the fish and/or adequately remove the metabolites, it is clear that some re-use of the water is needed. Liao (1971) provided an example of oxygen-based water supply quantity criteria which can be used to determine if reconditioning is needed for a given programme. Liao's criteria are summarized in Fig. 10 for salmon and trout[1].

Similar charts can be (and have been) prepared for other species in intensive culture and for other flow-related quality criteria, such as allowable ammonia levels.

While specific criteria may be disputed, it is clear that there are limits to minimum acceptable flow values. When these limits are reached, some form of water reconditioning is necessary.

[1] The species tested were: coho salmon (*Oncorhynchus kisutch*), chinook salmon (*O. tshawytscha*) rainbow, kamloops and steelhead trout (all *Salmo gairdneri*), cutthroat trout (*S. clarki*), and splake (*Salvelinus namaycush* × *S. fontinalis*)

TABLE II
A comparison of inflow rates, reconditioning efficiencies and calculated metabolite concentration for given Q and M values

Figure	*Type of system*	*Assumed rearing unit flow (Q) (l/min)*	*System inflow (l/min)*	*Assumed metabolite input (M) (g/day)*	*R*[a]	*E*[b]	*Calculated metabolite concentration (C × M/Q) (mg/l)*
9	Single pass	1 000	1 000		N/A	N/A	0·33
6	Simple reconditioning	1 000	330	480	0·67	0	1·0
7	Complex (open) reconditioning	1 000	200	480	0·8	0·15	1·0
8	Complex (closed) reconditioning	1 000	0	480	1·0	0·33	1·0

[a] R = portion of raceway water supply being reused
[b] E = efficiency of the treatment unit in removing or modifying a given metabolite

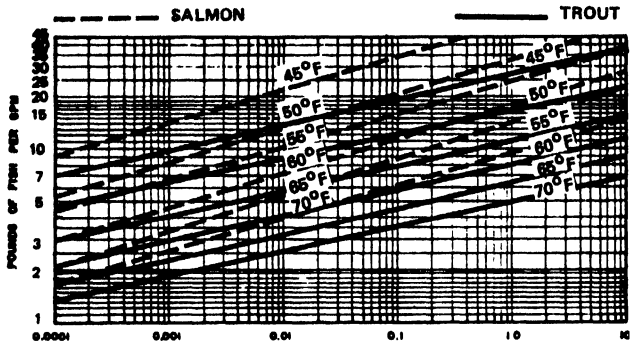


Fig 10. Required flow volume (at elevation 1 300 ft, dissolved oxygen concentration 95 percent saturated, minimum discharge oxygen content 5.0 mg/l or more)

3.3 *Water quality/economic criteria*

It is not always clear where reconditioning is made necessary by the relationship between water quality and economics. Examples of situations where water reconditioning is indicated, although ample water is available, are where: (*a*) Pretreatment is needed to remove pathogens and the unit cost of reconditioning treatment is less than the unit cost of pretreatment. (*b*) Heating is needed to meet programme growth goals, such as described by Lewis (1973), and a reconditioning system would reduce energy needs enough to offset added capital cost. (*c*) Post-treatment is a requirement for pollution control and unit reconditioning cost is less than unit post-treatment cost.

The specific answer as to what system best meets the quality/economic criteria is a function of the specific site, the proposed programme and the biological criteria used. Systems applied to specific situations are described elsewhere in this discussion.

4 Literature review

Water reconditioning for fish propagation can be classified into two categories—natural and artificial. A natural reconditioning system can be a stream or lake. Emphasis in this discussion, however, is on artificial systems such as those man builds for various fish cultural uses. Following is a description of some of the research work conducted by various investigators in this field.

Kawai, Yoshida and Kimata (1964 and 1965) reported the results of a study conducted on a goldfish aquarium of 18·5 gal capacity (70 l) with a recirculating system. A sand filter of 0·215 ft^2 (0·02 m^2) at 0·66 ft (0·2 m) depth was installed, and an air pump was used to aerate and recirculate the water at a rate of about 0·15–0·31 gal/min (0·009–0·019 l/sec). Water temperature was maintained at 22 ± 1°C. These authors found that: it required about two months for their aquarium to reach a steady state condition; both nitrification and denitrification took place simultaneously in the sand filter bed; and the nitrifying activity was highest in the upper layer of the bed. Hirayama (1965) also reported the results of water control by filtration through a sand bed in a marine aquarium with a closed circulating system. He indicated that oxygen consumption during filtration could be used as a satisfactory index in systematically evaluating the degree of purification of breeding water by filtration. In this experiment, the oxygen consumption by nitrification ranged from 34 to 53% of oxygen consumption during filtration.

Hirayama (1966) conducted a study to determine the rate of pollution of water by fish and the possible number and weight of fish kept in an aquarium. The possible relationships between fish by weight, feeding rate, rate of pollution, filter bed volume, filter hydraulic rate, and the size of sand were proposed based upon his test results.

Giudice (1966) described a recirculating water system built for spawning and hatching at the fish farming experimental station in Stuttgart, Arkansas. The capacity of the unit was 30 gal/min (1·9 l/sec). It consisted of two 1 000 Watt flexible immersion heaters, a centrifugal pump, a thermostat temperature controller, and three filters. Aeration was incidental as the water circulated. The author indicated that the system was satisfactory for flathead catfish fingerlings.

McCrimmon and Berst (1966) installed a semi-portable recirculating system at the University of Guelph, at Ontario, Canada, to rear young rainbow trout. The basic components of the unit included a centrifugal pump (capacity 20 gal/min or 1·26 l/sec), a sand filter, temperature control unit, an activated charcoal filter and an air compressor. After a 120 day study period, these authors indicated that the system had proved to be satisfactory for the laboratory production of rainbow trout. However, the loading rate of their study was only of the order of 1·26 lb of fish/gal/min (9·5 kg/l/sec).

Parisot (1967) described a seawater re-use system for laboratory test purposes. The filter bed (in addition to other components, such as the heat exchanger, pump, *etc*) consisted of a water distribution tray, 2 inches (51 mm) of crushed oyster shells, 2 inches (51 mm) of activated charcoal, 4 inches (102 mm) of coarse sand, 6 inches (152 mm) of gravel (1 inch or 25 mm diameter) and 10 inches (254 mm) of rock (2 inch or 51 mm diameter). The filter was backwashed periodically.

Chu and Greene (1967) described a bio-filter used for removing wastes from fish tanks for re-use. The bio-filter system consisted of a 39 cm diameter bucket with a perforated bottom filled 35 cm deep with washed gravel of 0·5–5 cm in diameter. A 2 cm layer of activated charcoal was spread on top of the gravel with a flow rate of 6 l/h. An air-lift pump was used for pumping water from three settling bottles (in series) to the top of the bio-filter.

Burrows and Combs (1968) reported on a water-reconditioning system built at the Abernathy (Washington) Salmon Cultural Laboratory for Pacific salmon propagation. The system included filtration, aeration, temperature control and sterilization. The filter (downflow) consisted of 1 ft (0·3 m) of crushed oyster shell (1/4 to 3/4 inches or 6·4 to 19 mm) and 4 ft (1·2 m) of crushed rocks, and was loaded at 1 gal/min/ft^2 (0·65 l/sec/m^2) and backwashed about once a week. The backwashing lasted about 20 min and required 1·33 ft^3 (37·6 l) upsurging air/min/ft^2 of filter bed. Aeration was achieved by using aspirators. Each aspirator, serving a 4 ft^2 (0·37 m^2) area, discharged 125 gal/min at 10 psi (7·9 l/sec at 0·7 kg/cm) into water 5 ft (1·5 m) deep. The authors reported that the aspirator was able to raise dissolved oxygen to 90–100% saturation. The temperature control unit, consisting of a heat pump, was used to maintain water temperature at desirable levels. These authors indicated that a desirable ammonia level with 90–99% of the water recirculated could be maintained by use of this reconditioning system.

Kramer, Chin and Mayo, Inc. (1968) compared a 90% re-use recirculating-system hatchery to a single-pass hatchery in terms of capital cost and heating required to achieve equivalent production at a particular site in Michigan State, and concluded that neither system has a clear cost advantage.

Anon. (1968) reports that Dr. Gerhard Grünseid of Austria has raised trout fry and fingerlings in an indoor circulating water system. No large-scale application is indicated in the brief note.

Murphy and Lipper (1970) conducted a study on a treatment system (including three trickling filters filled with 1, 2 and 4 ft (0·3, 0·6 and 1·2 m) of shale or rocks) for channel catfish (*Ictalurus punctatus*) culture. These authors, as a result of their study, suggested the following design criteria for a filter: filled 4 ft (1·2 m) deep with 1/2 inch (13 mm) rock with a hydraulic loading of 3 gal/min/ft^2 (2 l/sec/m^2) and 2 ft^2 (0·19 m^2) of filter area required to support 50 lb of catfish.

In 1970, the State of Minnesota, Department of Conservation Fisheries Division, conducted a study on a water-reconditioning system—a horizontal filter installed at the St. Paul Hatchery. The filter, 2 ft^2 × 5 ft long (0·19 m^2 × 1·5 m long) filled with 1 to 2 inch diameter (25–51 mm) limestones, required backwashing about once a week. A bubbler aerator was provided to maintain a desirable DO level. About 10% of the water was wasted and had to be replaced with fresh water. In general, the test results were promising (Liao and Mayo, 1972).

Gigger and Speece (1970) also made a study on fish hatchery water-reconditioning, using an upflow filter ($10\frac{1}{2}$-inch or 267 mm diameter × 12 inch or 305 mm height) and a horizontal filter similar to that used at the St. Paul Hatchery. The filters, filled with 3/4 inch diameter (19 mm) gravel, removed ammonia ranging from 150 to 200 mg NH_3–N/ft^3/h (530 to 707 mg/100 l/h) at a temperature of 68°F (20°C and a hydraulic loading rate of 9·5–42·5 bed volumes/h compared with Burrows and Combs' system of 2 bed volumes/h. Unfortunately, the pumping facilities for the large-scale, horizontal filter became inoperable right after the system was started. As a result, the study on the horizontal filter system was not carried out.

Anon. (1971) reports that Aqua-Systems, Inc. has developed a water re-use system for the cultivation of channel catfish on a commercial basis, using a pre-filter, a bio-filter and aeration.

Anon. (1970) reports a laboratory-scale recirculating system used at the Unilever Research Laboratory for Dover sole (*Solea solea*). The system involves 95% re-use through 30 cm of mussel shells and 120 cm of crumbled granite. Heating, aeration and ultraviolet sterilization are also used.

Kramer, Chin and Mayo, Inc. (1972) prepared, for the Walla Walla (Washington) District Corps of Engineers, a study for the development of fish hatchery water-treatment systems. This study, conducted at the Federal hatchery in Bozeman, Montana, evaluated four different 50 gal/min (3·15 l/sec) pilot systems which were constructed on the grounds, and developed design criteria for the development of major units. These criteria were used in the development of a number of systems constructed since that time, some of which are described in the next section of this report. This study was directed both at reconditioning treatment and post-treatment, and placed some emphasis on pollution control (Liao, 1970 and 1972). The summary and conclusions of this study are repeated below (in slightly abbreviated form) to provide information on the criteria developed and to indicate the content of the study.

(*a*) In order to develop better treatment schemes for hatchery water reconditioning and pollution abatement, various water-treatment methods have been studied. Methods studied included an activated-sludge process, extended aeration, submerged filter and trickling filter. Formed plastic media ($3\frac{1}{2}$ inches or 90 mm in diameter) were used in the submerged and trickling filter studies. All are sufficient for pollution abatement based upon the present policy. However, in terms of water reconditioning and recycling for salmonid fish propagation, filter systems are more reliable.

(*b*) The efficiency of nitrification in a filter was found to be mainly a function of media retention time and solids level, providing the water temperature and pH were maintained within acceptable ranges. The efficiency is proportional to the media retention time. A retention time of 15–60 min (comparable to the existing units) is adequate for ammonia control. High levels of suspended solids (organic) have been found to interfere with the nitrifying performance of the filter. Therefore, the removal of most solids from water prior to entering a filter and the continuous removal of settled solids from the settling basin are necessary in order to assure proper ammonia oxidation.

(*c*) The filter performance is relatively stable once it reaches equilibrium. This is attributed to the absence of backwashing. (Backwashing is not required when the formed plastic media are used).

(*d*) The unit ammonia removal (NH_4/ft^2 or m^2 of media surface/day) by a filter is approximately the same, disregarding the size of media or whether the media are submerged or not, providing the same operating conditions are maintained.

(*e*) The acceptable maximum hydraulic loading of a filter can be as high as 2·5 gal/min/ft^2 or 1·7 l/sec/m^2 (which is 2·5 times higher than the previous criteria used at Dworshak) when the depth of the filter bed is 4 ft (1·2 m) or more.

(*f*) The maximum ammonia loading rate was found to be 20×10^{-5} lb NH_4–N/day/ft^2 or 1 g/day/m^2 (media specific surface area). When the ammonia loading rate exceeded this limit, the nitrification efficiency dropped dramatically due to the presence of high organic levels which support heterotrophic bacteria growth.

(*g*) A settling basin with a retention time of greater than 15 min was found to be sufficient for removing most of the settleable solids from water before it enters the filter.

(*h*) Aeration may or may not be required, depending upon whether the filter media are submerged or not. (No additional aeration is required if an elevated trickling filter is used.) The aeration, required when a submerged filter is used, may be accomplished by installing an aeration basin of 10 min retention time with an air supply rate of 0·3 ft^3 air/gal (0·008 m^3/3·78 l) water.

(*i*) Whether or not a buffering facility is required depends upon water quality. Buffering is not required when the alkalinity of the water is higher than 100 mg/l as $CaCO_3$. Buffering, when required, can be accomplished by placing crushed limestone or oyster shells in the aeration chamber or the filter bed.

(*j*) Thin-bed filters are not recommended because of a possible hydraulic short-circuiting and algal growth on the surface (which reduces the effective surface area for nitrification).

(*k*) Because of the development of nitrite build-up during the early stages of a new water-reconditioning system, a gradual increase of fish load is recommended in order to avoid fish mortality due to nitrite toxicity. The start-up time for a reconditioning system is dependent upon water temperature. With the normal temperature ranges used in salmonid rearing, the start-up time for a new facility may be one to two months. Start-up with chemical feed may be desirable where advance preparation is necessary.

Mayo (1972) reported on system costs at a large hatchery at Warm Springs, Oregon. There the reconditioning system had an estimated construction cost equal to approximately 20% of the hatchery cost or about US$ 40/gal/min.

Crocker (1972) reported for complex re-use systems (open) a capital cost in the range of US$ 50–80/gal/min.

Bardach, Ryther and McLarney (1972) described a broad range of reconditioning systems.

Kramer, Chin and Mayo, Inc. (1972) developed a theoretical analysis base for complex systems, combining mechanical processes, a lake and a groundwater system for the State of Michigan.

Combs (in US Army Corps of Engineers, Walla Walla Dist., 1974) reported on research at the Abernathy, Washington Federal hatchery in three rock-and-oyster bio-filters operating under normal hatchery conditions. At loads that simulate fully-loaded salmon hatchery operating conditions, the filters were able to maintain suitable water treatment conditions at 90–95% re-use.

Serfling, Van Olst and Ford (1974) reported on a recirculating culture system for larval American lobsters (*Homarus americanus*). This system is based upon a sand filter, a charcoal filter and direct heating. The circulating rate is 10 l/min. This unit can be operated as a closed or open system.

Risa and Skjervold (1975) reported on a prototype recirculating system which included sedimentation followed by limestone bio-filters. Preliminary conclusions were that growth and viability of Atlantic salmon (*Salmo salar*) smolts were satisfactory in that system.

Gaines (1975) reported on a proposed reconditioning system which would use breakpoint chlorination followed by dechlorination for ammonia removal. This 10 000 gal/min or 37 860 l/min system (for intensive culture of warm-water fish species) would cost US$800 000 in capital cost and US$ 70 000/year to operate. Ion exchange studied for the same system would cost about 40% more.

5 The major reconditioning systems in service

The technology described in a previous section of this report has, in part, been applied to a number of major reconditioning systems which have been constructed in North America. Table I describes these systems in detail (Source: phone inventory and Kramer, Chin and Mayo, Inc. study files).

Set out below is a summary tabulation of these systems.

6 Economics

The cost of a water-reconditioning system in a large salmonid hatchery is significant. Typically, 20% of the capital cost of a facility based upon complex water reconditioning is cost related to the reconditioning filter, pumps and aeration devices. This, however, is not an accurate measure of the economics of reconditioning systems and, in fact, no general statement can be made. The question is entirely site-specific and, on occasions, is not even a question that is discussed. Where a hatchery must produce a given number of fish and where the available water supply is inadequate to raise these fish on a single-pass basis, it is inevitable that reconditioning be imposed. Thus, the primary question is: what is the most economical reconditioning system? This too has answers as varied as the programmes that hatcheries are based upon or as the sites that hatcheries are built upon.

One study for the State of Missouri (Kramer, Chin and Mayo, Inc. 1973), however, provided an interesting economic comparison. Basically, the study said this: 'For a given propagation programme it would be more expensive for the State of Missouri to construct two hatcheries, each utilizing water supplies suitable for single-pass rearing, than it would be to select one of these two sites and build a hatchery suitable for the full programme, using reconditioning techniques'.

7 Research needs

In the description of major existing reconditioning systems in North America (Table I) it is clear that there is no common agreement as to the best recirculation system for

Facility	*Number of rearing units*	*Flow through each rearing unit*		*Total flow through rearing units*		*R (% of water re-used)*
		gal/min	*m³/day*	*gal/min*	*m³/day*	
Dworshak No. 1	25	600	3 252	15 000	81 300	0·90
Dworshak No. 2	25	600	3 252	15 000	81 300	0·90
Dworshak No. 3	34	600	3 252	20 400	110 568	0·90
Spring Creek	44	700	3 794	30 800	166 936	0·90
Coleman	30	420	2 276	12 600	68 292	0·90
Lahontan National Fish Hatchery	36	400	2 168	14 400	78 048	0·90
Capilano	10	600	3 252	6 000	32 520	0·90
Crystal Lake	10	600	3 252	6 000	32 520	0·95
Mad River	5	1 000	5 420	5 000	27 100	0·90
Fire Lake	Several	1 500	8 130	—	—	0·90
Sea Pool Fisheries	28	—	—	*10 000	54 200	0·80–0·95
Warm Springs, Oregon	39	750	4 065	22 500	121 950	0·90
Rathbun	20	940	5 095	18 800	101 896	0·50
Warm Springs, California	8	750	4 065	6 000	32 520	0·50
Bayfield Fish Hatchery	14	550	2 981	7 700	41 734	0·50
Alsea Steelhead Hatchery	20	500	2 710	10 000	54 200	0·50
Kooskia	6	600	3 252	3 600	19 512	0·90

* Estimated

aquaculture facilities. It is also clear that some of the systems are partial or total failures. Thus, it seems reasonable to expect that there are still a significant number of design problems to be solved. These design problems can be solved either by reference to research on similar water-treatment applications or by further research.

Undeniably, some of the past research in water reconditioning has 're-invented the wheel'. Work in the allied fields of sanitary and industrial engineering could have been better utilized by the aquaculture researcher. However, such engineering technology is not always applicable. An appropriate point to consider is that a fish's entire environment is water and, unlike man, he cannot escape a brief operational variation simply by not drinking it.

Following are a number of specific areas in which further research might be appropriate (US Army Corps of Engineers, Walla Walla District, 1974).

7.1 *Disease control*

7.1.1 *Incoming water supply.* In unprotected water supplies, often it is necessary to sterilize the water to eliminate pathogens harmful to fish. Major reconditioning systems currently utilize ultraviolet sterilization but such systems have, on occasions, not proved satisfactory. Ozonization has been suggested as a system which would provide both pathogen control on contact and toxic residual not found in ultraviolet methods. It has been suggested that ozonization would be especially effective in virus control.

7.1.2 *Internal to the system.* Even where sterilization is provided for the incoming water supply, it is not uncommon for diseases to be found in fish populations within a recirculating system. Thus, there is a need for methods that will allow the fish diseases to be treated within a system without reducing the system's effectiveness. Methods have been studied and a number have been used intuitively by hatchery operators with varying levels of success. There is a need for a rational comparison of various methods under similar conditions, with a measurement of the effects upon reconditioning systems themselves.

7.2 *Monitoring*

Water-reconditioning systems, even where the reconditioning is not especially effective, generally operate at relatively low concentrations of ammonia and nitrates, but the level variations are important. Most simple monitoring methods that have been devised are more appropriate to sanitary engineering, where the concentrations are higher. There is a need for a device that will allow continuous monitoring by the hatchery operator at the lower concentrations.

7.3 *Operating data*

There is a wide variation of operating units in both cold- and warmwater aquaculture facilities throughout the world. The data accumulated by researchers on: (*i*) the production of metabolites and (*ii*) the effectiveness of reconditioning systems are gathered from pilot units and are of doubtful validity for full-size operating units. A useful element of research would be the publication (in some consistent format), of operating data from a number of hatcheries operating under various conditions of load, water supply, need and climatic conditions. To allow this, it would be desirable that new hatcheries have flow-measuring devices and sampling taps built at appropriate points.

Often the most useful research that can be conducted is to compare the designer's assumptions with the actual performance of a facility after it has been constructed.

Of specific interest to a designer would be the effect of filter-bed geometry, void ratios and loadings. At the same time, it would be useful to have more detailed studies of bacterial populations in the biological filter systems.

7.4 *Sludge removal and disposal*

Many of the devices used for removing solids from reconditioning systems follow the pattern of sanitary engineering devices. This may or may not be appropriate, but the available devices certainly should be tested for applicability.

Also of concern are methods for utilization of the sludge generated in a fish hatchery. There is significant nitrogen in the sludge and it may have use as fertilizer or animal food.

7.5 *Water chemistry and nitrification*

There is a wide variation in nitrification rates at the ammonia concentrations and temperatures typically found in coldwater hatcheries. This variation may be related to pH and the other elements of water chemistry. Tables have been prepared, suggesting the toxic levels of ammonia (both in its ionized and un-ionized form). These are not entirely consistent and a body of rational data based upon long-term bioassays would be desirable.

7.6 *Aeration*

Numerous methods of aeration are used in fish hatcheries (both in reconditioning and single-pass systems), *ie*, aspirators, surface aerators, bubblers and other devices. Generally, the design of these devices has come from sanitary engineering technology, where the liquid was typically low in or entirely deficient of oxygen. It would be desirable to study other methods for the aeration of water with relatively high values of dissolved oxygen. Approaches that have been suggested include: (*i*) insertion of pure oxygen and (*ii*) high pressure injection of air at pump inlets.

7.7 *Nitrification of ammonia*

Nitrification of ammonia through biological methods has been investigated, and is being applied in many facilities. Other methods have been suggested, including the oxidation of ammonia directly through the use of ozone and/or catalytic devices. These deserve further investigation.

Ion exchange for nitrification has been suggested and to a degree quantified. It also deserves further study.

7.8 *Biological filter media*

There is a considerable variation in the material and geometry of media now being used for biological filters. They range from sand to rock, to plastic rings and styrofoam beads. There is a need, however, for investigation in this area, especially if it relates not just to the character of the media but also to the character of the basic water supply.

7.9 *Pond cleaning devices*

Numerous designers have suggested that water-reconditioning systems that have rearing units that allow solids to settle out (in the rearing unit) may provide significant economies by the elimination of sedimentation chambers. These require an economical means of cleaning the ponds which is not detrimental to fish. Although informal research

is being undertaken by many hatcheries, there seems to be no clear or best solution.

7.10 *Energy conservation*

Often the justification for a reconditioning system is to conserve energy in the modification of water temperature. There is a need for information, if not research, for ways to reduce the energy required for achieving the desired temperature modification. This might include solar ponds, better heat exchangers, pond covers and similar devices.

8 Prospects

The major prospects for the use of water reconditioning for aquaculture lie in[1]: (*a*) hatcheries producing migrant salmonids for ocean-ranching ventures: (*b*) hatcheries producing large quantities of high-quality fingerlings for sale to fish farmers: (*c*) the expansion of existing hatcheries with good quality, but limited water supplies. This applies especially to hatcheries well located in relation to major markets or to good ocean-ranching planting sites.

Much of the trout and catfish production of North America is based upon water supplies suitable for high-production, low-cost fish rearing. It is these hatcheries that establish the economic base against which other facilities must compete. It seems unlikely in the near future that production in direct competition with these existing facilities can be sustained on the basis of complex reconditioning systems.

[1] The author has a bias, expressed in earlier papers (Mayo, 1974), for ocean ranching and traditional forms of polyculture as practised in most of Asia and parts of Europe. This should be understood in considering his views of the prospects for water reconditioning (R D. Mayo)

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A Model Closed System for Aquaculture Incorporating the Recycling of Wastes[1]

R. A. Neal and C. R. Mock

Abstract
Much aquacultural research is conducted without the use of appropriate model systems. Models of aquaculture systems can be valuable aids in measuring the value of supplemental inputs planned to increase production per unit of area. The complex interactions occurring among the many factors influencing production are particularly difficult to evaluate without adequate control. An intensively regulated model can be used to obtain necessary control.

An example of a model closed system is discussed and observations are made regarding those inputs to the system which have been most valuable for the high-density culture of penaeid shrimp

It is hoped that this paper will encourage: (*i*) the use of models to explore the benefit of environmental control in aquaculture; (*ii*) definition of various inputs and environmental parameters by researchers so that results can be used by others; and (*iii*) investigation of innovative and sophisticated approaches to environmental control for aquaculture.

Un modèle d'aquaculture en système clos incorporant le recyclage des effluents
Résumé
Une bonne partie des recherches aquicoles est effectuee sans recours à des modèles de systèmes appropries. Les modèles de systèmes aquicoles peuvent constituer d'utiles auxiliaires pour mesurer la valeur des inputs supplémentaires auxquels il est prévu de recourir pour accroitre la production par unite de surface. Les interactions complexes qui interviennent entre les nombreux facteurs dont depend la production sont particulièrement difficiles à evaluer sans temoin adequat. L'on peut utiliser un modèle rigoureusement contrôle pour obtenir le temoin necessaire.

L'auteur examine un modèle de système clos, et communique des observations concernant les inputs ajoutés au système qui se sont reveles les plus utiles pour l'elevage en forte densite de crevettes peneides.

L'on espère que ce document encouragera: (*i*) l'emploi de modèles pour etudier les avantages du contrôle de l'environnement dans l'aquaculture; (*ii*) la definition de divers inputs et paramètres ecologiques par les chercheurs de manière que leurs resultats soient utilisables par d'autres; et (*iii*) l'etude de methodes novatrices et modernes applicables au contrôle de l'environnement dans l'aquaculture.

Modelo de sistema cerrado para acuicultura, con reciclaje de desechos
Extracto
Son muchas las investigaciones acuícolas que se realizan sin emplear modelos adecuados Los modelos de sistemas de explotacion acuícola pueden constituir una ayuda valiosa para medir el valor de los insumos suplementarios que tienen por objeto aumentar la producción por unidad de superficie. Especialmente difícil es evaluar, sin un control adecuado, las complejas interacciones que se producen entre los muchos factores que influyen en la producción. Para lograr el control necesario puede utilizarse un modelo regulado intensivamente.

Se examina un ejemplo de modelo de sistema cerrado y se hacen algunas observaciones sobre los insumos al sistema que se han demostrado más útiles para el cultivo de camarones peneidos en grandes densidades.

Se espera que este documento fomente: (*i*) el empleo de modelos para explorar los beneficios del control del medio ambiente en la acuicultura; (*ii*) la definición de los diversos insumos y de los parámetros ambientales por parte de los investigadores, de modo que sus resultados puedan ser aprovechados por otros; y (*iii*) el estudio de enfoques innovadores y perfeccionados del problema del control del medio ambiente para la acuicultura.

1 Introduction

In most aquacultural activities some costs are related to space requirements. Consequently, a significant proportion of aquacultural research and development is aimed at increasing the production per unit of area. In fact, a commonly used measure of success is a statement of the production per unit area.

Unfortunately, much of the research directed toward refinement of culture systems to improve production has been trial-and-error testing of various inputs under poorly controlled conditions. There has been a notable absence of functional models in which parameters can be controlled and supplemental inputs evaluated effectively. The typical outdoor pond is not entirely satisfactory as a model because factors influencing production (eg, weather, disease, predation, competition and the general ecology of the pond) frequently cannot be controlled. The effects of uncontrolled variables interacting with the experimental variables complicate the interpretation of results, sometimes to an extent that actual relationships between the organism and its environment cannot be determined.

In addition to the value of model systems in evaluating inputs and understanding the complex interactions among various inputs, models are useful in providing a framework for conceptualizing a system and planning experimentation. An intensively regulated model can provide many clues to the correct management of less intensively managed systems. The increased use of model aquaculture systems in teaching and demonstration situations should be encouraged.

2 Characteristics of a model aquaculture system

Since man has had more experience with terrestrial animals than with aquatic animals, it is logical for him to look at the most successful terrestrial animal husbandry systems to predict the kinds of controls which will be economical in aquaculture. The chicken industry has developed highly controlled systems with consequent production of a low-priced product. Many of the controls successfully and economically exercised in the chicken industry are usually not exercised by aquaculturists. Some examples of these are: elimination of predation, effective treatment of disease, breeding of genetically superior strains, and complete control of food intake.

Functional experimental models should be designed so that measurements can be made of the effects of varying levels of inputs of several types. The interactions or synergistic effects of these inputs may also occur and need to be understood. Although any single model may not be adequate to evaluate the effects of all inputs, a classification of inputs is listed below as a guide to the design of suitable models.

(*a*) Stocking: (*i*) Density (*ii*) Variety and strain (*iii*) Species combinations

(*b*) Feeding: (*i*) Presentation of prepared feed –Type – Amount (*ii*) Growth of natural foods (*iii*) Fertilization to promote plant and animal growth

(*c*) Aeration

(*d*) Water circulation

(*e*) Temperature control

(*f*) Chemical control: (*i*) Pesticides (*ii*) Herbicides (*iii*) Disease treatment

(*g*) Labour requirements

(*h*) Waste removal: (*i*) Water exchange (*ii*) Ecological recycling (*iii*) Filtration

Although not complete, this list of inputs serves to demonstrate the types of controls a researcher may wish to evaluate as well as the complexity of interactions which may occur. The researcher's ability to control parameters in a model system distinguishes the model from other systems

[1]*A contribution of the National Marine Fisheries Service, Gulf Coastal Fisheries Center, Galveston Laboratory, 4700 Avenue U, Galveston, Texas 77550, USA.*

in which the scientist can only monitor changes. As one learns to control research systems, a degree of standardization will be possible and research results from one location will have comparative value in other situations.

As the ability to measure and control these inputs improves in a model, so the ability to evaluate individual inputs is greatly enhanced. Because the costs of the various inputs vary greatly among geographical locations, the capability of measuring the value of these inputs in each location is needed.

3 Example of a model closed system

Because of the expense of land and labour in the United States, efforts have been made at the Gulf Coastal Fisheries Center in Galveston, Texas, to evaluate a carefully controlled closed raceway system. Initial models of the system were described by Mock, Neal and Salser (1973).

The system has evolved as techniques for the control of environmental conditions and waste removal have improved. In most cases existing water treatment technology has been modified only slightly for the special applications of marine aquaculture (Mock, Ross and Salser, 1975; Mahler, Groh and Hodges, 1975). A recent model is a portable tank lined with plastic with a floating centre wall which supports airlift pumps. The detailed techniques will not be discussed in this paper since this information is reported in Mock and Neal 1975; the approaches taken and the principles incorporated into this model to date are outlined below.

A high level of control over the animals held in this model is possible because the tank is completely drained between experiments and water is filtered when the system is filled. The system is closed and plastic tank covers are used virtually eliminating predators and competitors.

A formulated pellet ration is fed at predetermined rates to shrimp in this system. The rations (Zein-Eldin and Corliss, 1979) have been shown to produce good growth in penaeid shrimp for extended periods. Although algae and small invertebrates grow in the system, the artificial feed is the primary source of food for the shrimp. Stability of some feed pellets has been a problem because of continuous water movement and associated rapid disintegration of the feed; however, this problem was corrected through the use of an alginate binder. Decomposition of feed and shrimp wastes are uncontrolled sources of fertilization; however, no other fertilizers were used.

The aeration system used is an airlift pump system described by Mock, Neal and Salser (1973) and Mock, Ross and Salser (1975). Its heavy aeration has been sufficient to maintain oxygen levels at the saturation level continuously during experimentation in all parts of the raceway. In addition to the beneficial value of constant, high levels of oxygen to the cultured animals, the aeration also oxidizes the wastes rapidly and prevents the formation of anaerobic conditions throughout the system.

Water circulation is created with this pump system by attaching elbows to the upper end of each airlift. This creates a current the direction of which can be adjusted by changing the angle of the elbows. The tank design (rectangular with rounded ends and a centre wall) was chosen because of circulation patterns occurring in the tank. Sufficient current velocities are maintained to keep particulate wastes suspended in the water column.

In Texas, winter temperatures are too low for penaeid shrimp, therefore, the water is heated to maintain suitable temperatures year round. A closed system is used rather than exchanging water to avoid unnecessary heat loss. Temperature control is accomplished through shading, solar heating and with a gas-heated heat exchanger during cold weather. Water temperatures have been maintained within a range of about 4°C when this system was functioning properly.

No chemical control has been used in the system although its size (43,000 l) and the fact that no water is exchanged would enhance evaluation of chemical control techniques.

Labour requirements, which can be measured for any system, are related to the levels of control exercised, the degree of automation, and the design of the model. The evaluation of labour input is not necessarily simplified by the use of a model system.

The closed system has the advantage of producing no effluent, but it does require elaborate waste treatment to maintain suitable water quality at high stocking levels. For this purpose a variety of physical and biological filters have been tested. Those used in the present model are: an inclined plate separator for removal of particulate wastes; a protein skimmer; and a biodisk filter for removal of dissolved wastes (Mock and Neal, 1975). One factor considered in the selection of these filters was the ease of recovery of filtered wastes and biological growths, since these can be utilized.

Although this model is still in the developmental stages, the use of the system has helped evaluate various forms of environmental control.

The beneficial effects of the following inputs have been surprising: aeration, water circulation and waste removal by filtration. Waste removal by filtration has been difficult to measure and standardize, but Ross, Mock and Salser (1975) have obtained preliminary data on the effects of small filters on the chemical nature of filtered water.

4 Discussion

There has been a reluctance among aquaculturists to explore the use of high-density culture systems. Reasons given for the lack of experimentation with intensive, controlled systems are: high initial costs; the projected large energy inputs required; and the level of technology required to operate the systems. None of these is an adequate rationale to discourage the use of intensive models for the purposes already described. In fact, models should be used to study methods of increasing production without excessive capital investment, high energy requirements or complicated technological input.

If aquaculturists are willing to depart from traditional constraints and seriously consider new and more progressive approaches to aquaculture, there are many opportunities to increase control of systems without excessive expenses. For example, techniques for the efficient use of solar energy and wind are being developed rapidly, and these uses may involve relatively low costs. Circulation of water within a pond or tank has many desirable effects, but the uses of wind, tides or water power for this purpose have not been explored thoroughly. The use of aquacultural wastes to produce methane for fuel is another area which seems to offer considerable potential with present technology and

relatively low investment costs. Numerous other possibilities exist for the economical application of engineering technology to aquaculture.

If the full potential of the husbandry of aquatic plants and animals is to be realized we must be willing to develop a new technology which will offer means of controlling the organism cultured and its environment. The use of models will aid in this development.

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An Experiment in Growing Rainbow Trout in Recirculated Water

T. K. Hill

Abstract

Techniques were investigated for culture of rainbow trout (*Salmo gairdneri*) in a recirculated water system during the winter months in south Georgia, USA. After a 129 day culture period, trout fingerlings stocked at densities of 17·8 m^{-1} increased from an initial mean weight of 54·5 g to a mean harvest weight of 253·9 g. Water temperatures ranged from 5 to 25°C. Although water quality deteriorated to some extent as it flowed through the raceway, none of the parameters measured was considered detrimental to to the fish. Growth data for the trout indicated that, where surface water is used, a growing season of at least 100 days with water temperatures between 10 and 25°C is needed for them to reach harvestable size. Mean feed conversion ratio and survival were 1·3·1 and 93% respectively.

Expériences d'élevage de truites arc-en-ciel dans de l'eau recirculée

Résumé

On a etudie les techniques d'elevage de truites arc-en-ciel (*Salmo gairdneri*) dans un système en circuit ferme, en hiver, en Georgie du sud (Etats-Unis). Après 129 jours, les alevins de truite stockés à raison de 17·8/m^3 sont passés d'un poids moyen initial de 54·5 g à un poids moyen final de 253·9 g. L'eau était à des températures de 5 à 25°C. Bien que la qualité de l'eau se soit quelque peu altérée a mesure qu'elle traversait le raceway, aucun des paramètres mesures n'a été juge de nature à pouvoir porter atteinte aux poissons. Les données relatives à la croissance des truites indiquent qu'en eau de surface, il faut prévoir une période de croissance d'au moins 100 jours, à des températures de 10 à 25°C, pour que les poissons atteignent leur taille définitive. Les taux moyens de conversion alimentaire et de survie étaient de 1·3:1 et 93% respectivement.

Experimento de cría de trucha arco iris en aguas recirculadas

Extracto

En el sur de Georgia (EE.UU.) se han estudiado algunas técnicas para el cultivo de trucha arco iris (*Salmo gairdneri*) durante los meses de invierno en un sistema de agua recirculada. Al cabo de un periodo de cultivo de 129 dias, jaramugos de trucha de un peso medio inicial de 54·5 g, sembrados a razon de 17·8 por m^3, alcanzaron un peso medio de 253·9 g. La temperatura del agua osciló entre 5 y 25°C. Aunque la calidad del agua se deterioró algo, a medida que el agua fluia por los canales, ninguno de los parámetros medidos se consideró nocivo para los peces. El estudio del crecimiento de las truchas revela que, utilizando agua procedente de la superficie, es necesario, para que los peces alcancen una talla explotable, que la temporada de cria dure al menos 100 dias, con aguas a temperaturas entre 10 y 25°C. Los indices medios de conversión de piensos y supervivencia fueron, respectivamente, 1·3:1 y 93%.

1 Description of the study area

The Coastal Plain Experiment Station, where this experiment was conducted, is located at Tifton, Georgia, about midway between 31° and 32°N latitudes in the coastal plain region of the state. This area is a part of the temperate zone; surface water temperatures during the winter months are similar to those of cold climates during the summer months. For this reason, cultures of rainbow trout (*Salmo gairdneri*) in the winter months in the temperate zone could be used as another cash crop for fish farmers who grow channel catfish (*Ictalurus punctatus*) or some other warm-water species during the summer months. The object of this investigation was to test the feasibility of growing rainbow trout from fingerling to marketable size in recirculated water without the use of underground water to elevate the water temperature during cold days and nights.

The facilities used in this study were a closed loop or recirculation system. Hill, Chesness and Brown (1973) described the system in detail. The system was originally designed and built for channel catfish production research. Since channel catfish do not grow in cold water, the practice of culturing rainbow trout during the winter season was evaluated.

The components of the system were a 152·0 m deep well, a storage reservoir with an area of 2·0 ha with an average depth of 1·2 m and an earthen channel raceway divided into eight 30·4 m long segments by concrete headwalls. The well was equipped with a 40 hp motor which delivered 600 gal/min (2·27 m^3/min) to the reservoir. Well water was used only to fill the reservoir. The reservoir was encircled with a diversion channel so very little surface water got into it from rainfall. Water was electrically pumped from the reservoir to the head of the raceway at the rate of 530 gal/min (2·0 m^3/min). The water flowed through raceways and back to the reservoir by gravity. Each of the eight segments contained about 126 m^3 of water.

2 Methods and materials

Rainbow trout fingerlings from a private hatchery in north Georgia were stocked in the raceways at the Coastal Plain Experiment Station on 15 November 1972. The fingerlings ranged from 152 to 203 mm in length and had a mean weight of 54·5 g. The stocked weight per raceway segment was 125·9 kg or approximately 2 250 fish at a density of 17·8/m^3.

A commercial floating trout feed approximately 6 mm in size was fed to the fish twice daily in equal amounts at 08·30 and 16·00 hours for 129 days. The amount of feed given the fish was based on: water temperature, bi-monthly sample weights of fish, estimated conversion ratio of feed to fish and acceptance of the feed by the fish.

Feed treated with 4·5 g active ingredient tetracycline hydrochloride per 45·4 kg fish was fed for 10 days post-stocking as a precaution against bacterial infection from stress. Dissolved oxygen, total hardness, pH and ammonia were measured weekly.

A nylon seine 9·1 m long with 12·7 mm mesh and a 1·2 m bag was first used to harvest most of the trout. Each raceway segment had a 2·4 mm shear valve which was opened to drain the water and recover the fish which escaped the seine. Harvest took place during the period 14–26 March 1973. The fish were sold either to processors or to live haulers for re-sale in fish-out ponds in north Georgia.

3 Results and discussion

Water temperatures are a factor which must be considered not only because they should remain low enough for survival and health of trout in temperate zone waters, but also because there must be enough warmwater days (water temperature at least 10°C) for the fish to make satisfactory growth during the five months of winter culture. Hill, Chesness and Brown (1972) used 21°C deep well water to maintain satisfactory growing conditions for trout during unusually cold days when the fish refused feed. Under most conditions, this practice would be prohibitive due to the cost of electricity and many fish farmers who would be interested in growing trout would not have a deep well.

A summary of water temperatures in the raceways is given in Table I. Water temperatures ranged from a low of 5° to a high of 25°C. The trout experienced the 25°C temperatures for four successive days with no apparent adverse effects. From this information, it appears that rainbow trout can withstand fairly high water temperatures so long as other water quality parameters are acceptable.

TABLE I
WATER TEMPERATURES (°C) IN RACEWAYS DURING THE 1972–73 TROUT GROWING SEASON, COASTAL PLAIN EXPERIMENT STATION, TIFTON, GEORGIA

Raceway	*Range* (°C)		*Mean* (°C)	
	Maximum	*Minimum*	*Maximum*	*Minimum*
1	7–22	5–21	14	12
2	7–22	5–21	14	12
3	7–24	5–22	15	12
4	8–25	6–23	15	14
5	8–25	6–22	16	13
6	9–25	6–22	16	13
7	9–25	6–23	16	13
8	10–25	8–19	15	12

Overall means: Maximum = 15°; Minimum = 13°C

When the water temperatures were below 10°C, the trout fed sparingly or not at all. During the 129 day culture period there were 25 days when water temperatures were less than 10°C. Even though the fish were stocked in mid-November and harvested during the last half of March, only 81% of the days had temperatures which promoted good trout growth.

None of the water quality measurements taken indicated deterioration to the point of detriment to the fish. Dissolved oxygen remained at or near saturation (range: 6·7–15·0 ppm). Total hardness of the water ranged from 45 to 95 ppm. Late morning pH values ranged from 5·7 to 6·9. Ammonia levels rose gradually as the water passed through the system, and ranged from 0·2 to 0·9 ppm on the first raceway segment and from 0·8 to 1·7 ppm in the eighth segment. This was expected since the metabolic wastes from the fish accumulated in the water as it flowed through the system. These data indicate that the carrying capacity of this system was not reached; thus it should be possible to grow greater densities of fish before water quality degradation would become a limiting factor.

Survival of the trout was 93%. Data in Table II show that 93·1% of the mortalities occurred during the first two weeks after stocking. Most of these losses were attributed to stress of the fish as they were hauled 483 km from the mountains of north Georgia. Losses during the remainder of the culture period were minimal.

Parasites and diseases presented no problem to the fish. Protozoan parasites (*Trichodina*) were found on gills of some of the fish shortly before harvest but treatment was never warranted.

Harvest data for the trout are presented in Table III. More than 2 000 fish were harvested from each of six of the raceway segments and more than 1 900 from the other two segments. The number of fish harvested plus those which died during the experiment totalled 18 084. Some of the segments had more than 2 250 and some had less, but the average number per segment was 2 260. It would be difficult to have more accurate estimates when fish are stocked by weight, even when closely graded fingerlings are used.

TABLE II
MORTALITIES OF RAINBOW TROUT DURING THE 1972–73 GROWING SEASON, COASTAL PLAIN EXPERIMENT STATION, TIFTON, GEORGIA

Month	*Raceway*								%
	1	2	3	4	5	6	7	8	
November	186	237	161	336	90	102	67	69	93·1
December	1	14	4	15	0	4	1	0	2·9
January	2	1	1	2	2	1	2	3	1·0
February	4	1	4	4	4	2	2	1	1·7
March	2	1	0	4	3	0	5	5	1·3
Total	195	254	170	361	99	109	77	76	

TABLE III
HARVEST DATA FOR RAINBOW TROUT GROWN IN RACEWAYS, COASTAL PLAIN EXPERIMENT STATION, TIFTON, GEORGIA (1973)

Raceway	*Number of fish*	*Weight of all fish (kg)*	*Mean weight (g)*
1	2 121	631	297·5
2	1 901	517	271·9
3	1 920	509	265·1
4	2 086	523	250·7
5	2 138	543	253·9
6	2 085	489	234·5
7	2 257	543	240·6
8	2 235	497	222·4
Total	16 743	4 252	253·9

The heavier mean weights of the fish in the upper raceway segments of the system were probably due to several factors. Harvest proceeded from lower to upper segments, thus, more days were provided for growth since the harvest was spread over a period of two weeks. Water cooled as it travelled through the system during cold days and nights resulting in less food consumption by the fish in the lower segments. Some days there was as much as 3°C difference

between the temperature of the water as it arrived from the reservoir and as it left the raceway.

Feed conversion ratios (weight of feed:weight gain of fish) ranged from 1·1:1 in segment seven to 1·4:1 in segment five with a mean of 1·3:1. These statistics are dependable since they are derived from actual weights of fish stocked, fish harvested and feed offered to the fish.

When fish culture systems of the type described in this study are used, water temperatures are dependent on the ambient air temperature to a greater extent than when underground water is used. A growing season of at least 100 days with water temperatures above 10°C is necessary for the fish to attain a commercial size when stocked at weights of 50–60 g. These fish had 104 days of active feeding and attained a mean weight of almost 254 g. Smaller trout than these would be unacceptable to most American processors.

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Mariculture in Controlled Environment Seawater Systems—A Review of Research at the University of Delaware (1968–75)

K. S. Price, M. R. Carriker, C. E. Epifanio, R. F. Srna, G. D. Pruder, E. T. Bolton and K. P. Smith

Abstract

The University of Delaware has been involved in the development of a closed or recirculated seawater system for the culture of commercially valuable filter-feeding bivalves This paper describes the evolution and major achievements of the Sea Grant sponsored research that was initiated in 1968. Recent accomplishments include growing the hard clam (*Mercenaria mercenaria*) and the American oyster (*Crassostrea virginica*) to market size completely on cultured and defined algal diets within one year. Present efforts involve development of the engineering refinement necessary to achieve a commercially viable system.

La mariculture dans des systèmes d'eau de mer en milieu contrôlé—les recherches en cours a l'Université du Delaware (1968–75)

Resume

L'Université du Delaware a participé à la mise au point d'une méthode de mariculture en système 'clos' c'est-à dire, un système de recyclage d'eau de mer pour l'élevage de bivalves filtreurs presentant un interêt commercial. Le present document decrit l'évolution et les principales réalisations du programme de recherche Sea Grant, qui a ete mis en oeuvre en 1968. Parmi les réalisations recentes figure la croissance, dans un délai d'un an, du hard clam (*Mercenaria mercenaria*) et de l'huître américaine (*Crassostrea virginica*) jusqu'à une taille commercialisable grâce à une alimentation fondee sur un regime à base d'algues de culture. Les efforts actuels portent sur les ameliorations techniques qui permettront de mettre au point un système rentable du point de vue commercial

Maricultura en circuitos de agua marina controlados—reseña de las investigaciones realizadas en la Universidad de Delaware (1968–75)

Extracto

La Universidad de Delaware ha trabajado en la preparacion de un circuito 'cerrado' de agua de mar recirculada para el cultivo de bivalvos comercialmente valiosos que se alimentan por filtración. En el documento se describen la evolucion y los principales resultados de estas investigaciones, patrocinadas por el Sea Grant y comenzadas en 1968. Entre los resultados más recientes figura la cria en un año de almejas (*Mercenaria mercenaria*) y de ostras americanas (*Crassostrea virginica*) de tamaño comercializable alimentándolas exclusivamente con algas cultivadas. Actualmente se trabaja para introducir las mejoras técnicas necesarias para conseguir un sistema comercialmente viable.

1 Introduction

Although man has practised various forms of aquaculture for thousands of years, most of his efforts have been directed toward manipulation of natural systems. However, experience in agriculture, which has the advantage of several hundreds of years of developmental effort, has shown that certain crops (*eg* poultry, winter tomatoes, mushrooms, many flowers) are best produced in artificial or otherwise highly controlled environments. It has become apparent that such may be the case with bivalve filter-feeding shellfish.

During the late 1800s, Delaware Bay, on the eastern coast of the US, produced 23 million lb (10·4 million kg) of oysters and had substantial shad, sturgeon, and other fisheries. Due to a variety of factors, including improper management of shellfish beds (harvesting without replenishment of equal quantities of shell stock), development of the watershed with attendant siltation, heavy industrialization of the Delaware River, industrial effluents and oil spills, mosquito control by ditching wetlands and spraying, and closure of harvesting areas due to sewage contamination, oyster production declined steadily to 9 million lb (4·1 million kg) by 1954. By 1960, the oyster industry in the Delaware Bay region suffered a catastrophic collapse due to a parasitic haplosporidian protozoan, (*Minchinia nelsoni*) familiarly known as MSX. In Delaware, the value of oyster landings declined from almost US$3 million to less than US$40000 in a few years (Maurer, Watling and Keck, 1971). What has happened to the oyster in the Delaware is an omen of what could happen to fisheries in other estuaries.

Based on the success of artificial propagation in agriculture, scientists at the University of Delaware decided to attempt to raise marine shellfish in a closed or recycled system having a high degree of environmental control. The long-range objective of Delaware's mariculture research is to produce desirable, fast-growing, palatable, nutritious oysters and clams, free of toxins and pathogens, in a controlled environment seawater system, at reasonable cost, unhampered by legal constraints, feeding the molluscs on algal and/or prepared foods using natural sources of energy, and recycling organic wastes. Introduction of new strains of shellfish and the successful exploitation of existing ones would provide the basis for establishment of a new shore-based marine food industry. The University of Delaware, College of Marine studies, mariculture programme on the Lewes campus was instituted to develop an economically and technologically viable prototype for industrial adaptation (Maurer, 1972; Epifanio *et al*, 1973; Epifanio, 1974, 1974a; Pruder, Epifanio and Srna, 1974).

Successful development of this prototype will, however, involve interdigitation of complex biological, chemical, and engineering materials and processes. Many biological and chemical aspects of mariculture research are extremely intricate, comparable, in a sense, to some of the research which resulted in the construction and maintenance of life-support systems for human flights in outer space.

Thus designing a pilot mariculture plant is not a simple matter of scaling up an already workable technology, but includes the development of biological and chemical principles and data as well. Our current biclogical and chemical research focuses on just these problems in order to provide engineers with the information they require in developing the prototype.

The design, construction, and operation of a controlled environment shellfish mariculture prototype is based on the following considerations: (*i*) need of a strictly non-toxic physical system of economically and biologically optimal size and configuration; (*ii*) behavioural characteristics, densities, and interactions of shellfish; (*iii*) specific nutritional requirements of shellfish at various stages in their life history; (*iv*) maximal limits of shellfish wastes consistent with a desirable marketable shellfish product; (*v*) recurring danger of blooms of microbiota resulting from dense populations of shellfish, and risks of outbreaks of shellfish diseases; (*vi*) elimination of biota potentially pathogenic to or parasitic in humans; (*vii*) the constantly changing rates of concentrations and combinations of mineral and organic chemicals in sea water.

To our knowledge, no other group of investigators is engaged in such extensive investigations to develop controlled environment shellfish mariculture.

2 History of Delaware research

Research in mariculture at the University of Delaware was initiated in September 1968, under the direction of Dr K Price and Dr D Maurer (Price and Maurer, 1969).

During the first three years (1968–71), success was achieved in conditioning broodstock, spawning parents at will, rearing larvae to setting, and growing oysters for six months on natural plankton (Maurer and Price, 1968; Price and Maurer, 1971; Keck *et al*, 1971; Maurer, 1972). Agricultural engineers fed starch and protein to oysters, but with little success (Dwivedy, 1972). Small recirculating systems were constructed, but chemical data were insufficient to gauge performance of the systems, and survival of oysters was poor (Dwivedy, 1973, 1974).

During the fourth year (1971/72), under the charge of Dr C Epifanio, improved methods for setting of larvae were explored, methods for prevention of gas bubble disease were developed (Malouf *et al*, 1972), and an assimilation efficiency study of oysters fed on the alga *Phaeodactylum* was completed. An engineer joined the team and most of the design and construction of the present Maricultural Laboratory was completed and a specification manual was published (Pruder, Epifanio and Malouf, 1973). The first two recirculating systems were built, loaded with finfish, and monitored for chemical data (Srna *et al*, 1973). In addition, preliminary experiments were directed toward maintaining the blue crab (*Callinectes sapidus*), in a recirculating culture system (Winget, Maurer and Anderson, 1973; Winget *et al*, 1976).

During the fifth year (1972/73), an algal culturist joined the group and the algal culture system currently in use was established. Postlarval clams and oysters reared in the laboratory were maintained in recirculating sea water and fed different diets of cultured algae; growth of the clams during the first six months was 50% faster than in nature (Hartman *et al*, 1974). Two more large recirculating systems were constructed. A physical chemist joined the team. The present water-quality laboratory was established and the use of an ammonia electrode was demonstrated in seawater analyses (Srna *et al*, 1973). Alkalinity problems in the recirculating system were identified, and a solution was implemented (Epifanio *et al*, 1973).

During the sixth year (1973/74), growth studies continued of clams and oysters fed selected species of laboratory-raised algae in recirculated sea water, and the shellfish approached market size. This was the first time anywhere that oysters and clams had been grown successfully in a recirculating seawater system (Epifanio and Mootz, 1975). Preliminary biological specifications for construction of a commercial system were developed (Epifanio, Srna and Pruder, 1975). Studies of tolerance of clams and oysters to their own waste products, particularly ammonia, were completed (Epifanio and Srna, 1975), and feeding rates of oysters were determined. The chemical kinetics of small-scale marine biological filters were characterized (Srna and Baggaley, 1975), the use of chloride, calcium, and divalent electrodes to maintain major ion balance in recirculating sea water was demonstrated (Srna, 1974), and preliminary data on production of ammonia by active and sedated shellfish were collected (Srna and Baggaley, 1975a).

During the seventh year (1974/75), additional investigators were attracted to the programme to fill in the following critical areas of investigation which were not yet adequately covered: prepared feeds, algal culture and kinetics, microbiology, ozonization, engineering, and legal aspects of mariculture. Clams and oysters were grown to seed size in recirculating seawater systems, and hard clams (*Mercenaria mercenaria*) and American oysters (*Crassostrea virginica*) were raised to edible market size, exhibiting a growth rate approximately three times that of the fastest reported growth of the species in Delaware Bay. Studies of the assimilation efficiencies of clams and oysters fed different algal diets were begun, as were exploratory studies on preparation and feeding of formulated feeds (Epifanio, 1976; Epifanio, Logan and Turk, 1976). Preliminary growth studies of four species of algae were carried out, and study was begun of nutrient utilization by a weed species and a good food species in chemostats relative to particulate carbon, nitrogen, and chlorophyll as a function of growth. Bacteria were isolated and characterized from algal cultures and recirculating seawater systems and correlated with water quality. Simulation of massive lysis of algal cultures using bacteria and their metabolic products was begun. A virus concentrator was constructed. Studies of nitrification kinetics and a new modular nitrification filter design were completed (Srna, 1975). A high density small-scale recirculating seawater system was designed and constructed (Srna, 1976). A rate equation for metabolic production was integrated and solid waste production rate experiments were initiated (Srna and Baggaley, 1975a; Srna, Baggaley and Ewart, 1975). Equipment and facilities were set up for bench-top studies on the application of ozonization in the treatment of mariculture fluids. Significant increase was obtained in mass algal production. The design and construction were completed and operation of a four bushel shellfish closed-cycle prototype was begun (Pruder *et al*, 1976). Design and construction of a 50 bushel prototype was started. Significant reductions were achieved in make-up water, waste treatment and make-up nutrients in the small prototype. A study of legal problems of new product development for closed-cycle mariculture in

the Delmarva region identified Delaware as being particularly suited to the establishment of commercial mariculture from the point of view of fishery law.

Priorities for research have been established by the functional group leader and the research team in consultation with local administrative leaders and with the advice of visiting review groups. Three years ago, priorities were further clarified by the use of a modified PERT analysis; during the first two years, priorities have been updated by similar analyses.

3 Current status and possibilities

The mariculture research and development team has demonstrated that it is possible to raise clams and oysters successfully in controlled environment recirculated seawater systems; has further refined several good algal diets which support rapid growth; and has demonstrated that certain 'weed' species of algae are unsuitable shellfish foods (Pruder *et al.* 1976). However, culture of massive volumes of desired species of algae necessary to develop controlled environment shellfish mariculture to a commercially viable system has yet to be achieved. Efforts are thus being redoubled to do this reliably. Since it is not known whether the necessary quantities of algae can be grown, additional emphasis is being placed on identification of nutritious formulated diets for possible supplemental feeding or as a possible substitute for algal foods (Price, Shaw and Danberg 1976).

Although current research has shown that growing shellfish in closed or recycled systems is technically possible and that economic feasibility is within reach, a substantial amount of research and development remains to be done to achieve commercial success and to bring mariculture systems to the level of sophistication that has been achieved with agricultural systems.

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Fish Culture in a Recirculating System with Water Treatment by Activated Sludge

Ch. Meske

Abstract

A method is described of keeping, feeding and propagating warmwater food fish in a closed and heated water system independent of climatic influences and environmental pollution.

Effluent from fish tanks passes into an aerated activated sludge tank where aerobic micro-organisms decompose the protein-containing sludge particles in the waste water. Nitrifying bacteria then oxidize nitrogenous excrements and feed residues to ammonium nitrogen and to nitrite and then to nitrate. The sludge next flows into a sedimentation tank without aeration where it settles to the bottom. Denitrification takes place here under anaerobic condition, nitrogen is set free, and the gas escapes. The sludge sediments are constantly pumped back to the sludge

tank. The purified water continues through a heating and pumping tank and back to the fish tanks. Water losses are compensated for by addition of well water.

More than ten years of experience with this system has shown that toxic values are not exceeded with respect to ammonium nitrogen, nitrite or nitrate, for common carp (*Cyprinus carpio*), grass carp (*Ctenopharyngodon idella*) and European catfish (*Silurus glanis*). However, another denitrification tank (non-aerated but with a sludge stirrer) can be added to provide optimal conditions for more sensitive fish species.

Fish can be reared in this system at a high stocking density, whereby optimal utilization of the capacity of the circuits is obtained when the stocking density is as constant as possible. When kept throughout the year at a water temperature of 23°C, common carp, grass carp and European catfish grow in one year from the egg stage up to 1·5–2 5 kg.

Pellets are used for feeding. The positive effect of green algae (*Scenedesmus*) as an additive to a fishmeal-free basic food was demonstrated by the experiments. Such a food mixture has proved at least equally as good as conventionally manufactured feeds.

If kept in water of 23°C throughout the year, common carp will become mature after about one year, and can spawn several times a year.

Attention is drawn to the application of this method to commercial fish production.

Elevage de poissons dans un système de recyclage avec traitement de l'eau par boues activées

Reśumé

Le document décrit une methode de conservation, d'alimentation et de propagation des poissons comestibles en eau chaude, dans un système clos alimenté en eau réchauffée, qui échappe aux influences climatiques et à la pollution de l'environnement.

Les effluents des réservoirs à poisson passent dans une cuve de décantation activée par aération où les micro-organismes aérobies décomposent les particules de boue chargees de protéines contenues dans les eaux usées. Les nitrobactéries oxydent alors les excréments azotés et les résidus alimentaires en azote ammoniacal, puis en nitrites, puis en nitrates. Les boues s'écoulent ensuite dans une cuve de sédimentation sans aération où elles se deposent au fond. La denitrification se produit alors en anaerobiose, l'azote est libéré et le gaz s'echappe. Les sediments boueux sont constamment renvoyés par pompage à la cuve de decantation. L'eau purifiée passe dans un réservoir où elle est chauffée et renvoyée par pompage aux réservoirs à poisson. Les pertes hydriques sont compensées par l'adjonction d'eau de pluie.

L'experience acquise depuis dix ans grâce à ce système a montré que la concentration en azote ammoniacal, en nitrites ou en nitrates n'excède pas les normes de toxicité pour la carpe commune (*Cyprinus carpio*), pour la carpe chinoise (*Ctenopharyngodon idella*), ni pour le poisson-chat européen (*Silurus glanis*). Toutefois, l'on peut ajouter au dispositif une autre cuve de dénitrification (non aeree, mais dotée d'un barboteur pour la boue), de manière a réunir les conditions optimales pour les espèces de poisson les plus sensibles.

Ce système permet l'élevage des poissons a de fortes densites de peuplement, et l'on atteint la capacité optimale d'utilisation du circuit lorsque la densité de peuplement est aussi constante que possible. Lorsqu'ils sont gardés pendant toute l'année à une température de 23°C., la carpe commune, la carpe chinoise et le poisson-chat europeen passent en un an du stade de l'oeuf à un poids de 1·5–2·5 kg.

L'on utilise des granulés pour l'alimentation des poissons. Nos expériences ont démontré l'action positive de l'algue verte (*Scenedesmus*) comme additif d'une alimentation de base exempte de farine. Un tel mélange s'est révélé d'une valeur au moins égale aux aliments des poissons de farbication courante.

La carpe commune, si elle est gardee pendant toute l'année dans une eau d'une température de 23°C, atteint la maturation après environ 1 an et peut frayer plusieurs fois en une annee.

Le document attire l'attention sur l'application de cette méthode à la production commerciale du poisson.

Cultivo de peces en un sistema de recirculación con tratamiento del agua con cieno activado

Extracto

Se describe un método para mantener, alimentar y reproducir peces de aguas cálidas destinados al consumo en un sistema cerrado de agua caliente, independiente de las influencias climáticas y de la contaminación ambiental.

Las aguas que salen de los tanques piscícolas pasan a un tanque aireado de cieno activado, donde micro-organismos aerobios descomponen las particulas proteínicas de cieno presentes en el agua. Sucesivamente, las bacterias nitrificantes oxidan los excrementos nitrogenados y los residuos de alimentos, transformándolos en nitrógeno amónico y luego en nitritos y nitratos. El cieno pasa después a un tanque de sedimentación, sin aireación, donde se deposita en el fondo. En él se produce la desnitrificación, en medio anaeróbico; el nitrógeno queda libre y el gas sale. Los sedimentos de cieno se devuelven constantemente por bombeo al tanque de cieno. El agua purificada pasa a través de un tanque de calentamiento y bombeo, y vuelve a los tanques piscícolas. Las pérdidas de agua se compensan añadiendo agua de pozo.

Más de 10 años de experiencia con este sistema han demostrado que, por lo que se refiere a nitrógeno amónico, nitritos o nitratos, no se superan los valores tóxicos para la carpa común (*Cyprinus carpio*), la carpa herbívora (*Ctenopharyngodon idella*), y el bagre europeo (*Silurus glanis*). De todas formas, puede añadirse otro tanque de desnitrificación (sin aireación, pero con un mecanismo para agitar el cieno) para obtener condiciones óptimas para especies de peces más sensibles.

En este sistema es posible criar peces a gran densidad de siembra: el aprovechamiento óptimo de la capacidad del circuito se obtiene manteniendo la densidad lo más constante posible. Manteniendo todo el año la temperatura del agua a 26°C, la carpa común, la carpa herbívora y el bagre europeo crecen en un año desde el huevo hasta 1·5–2·5 kg.

Para la alimentacion se usan piensos granulados. Estos experimentos han demostrado el efecto positivo de las algas verdes (*Scenedesmus*) como aditivo al alimento básico (un pienso sin harina de pescado). Esta mezcla ha resultado al menos tan buena como los piensos tradicionales manufacturados.

Manteniendo el agua a 23°C durante todo el año la carpa común llega a la madurez al cabo de un año, aproximadamente, y puede desovar varias veces al año.

Se señalan las posibilidades de aplicación de este método a la producción pisícola comercial

1 Introduction

In many parts of the world the production of freshwater fish is handicapped by climatic conditions. This is mainly the case in countries of temperate climate with cold winters (*eg*, Central Europe) where growth of warmwater food fish is limited to the summer months. Such conditions have prompted the development of a technique that enables experiments with fish throughout the year, independently of climatic conditions and without the deleterious effects of environmental pollution (Sengbusch, Meske and Szablewski, 1965). This technique permits continuous, controlled fish culture and continual implementation of experiments in the fields of physiology, reproductive biology, fish feeds and other aspects of fish culture (Meske, 1973). At the same time it forms the basis for actual food fish production throughout the year, independent of climate and environment.

2 Description of the system

The basis of this technique is a closed, permanently-heated water circuit with a constant temperature and biological water purification by activated sludge (Fig. 1). The water flows continuously through the fish tanks, constructed of glass, plastic, asbestos cement or other materials, and fitted with inlet and outlet devices. The polluted water which flows out of the tanks is carried through collecting pipes into a biological purification plant, which consists of: (*i*) a tripartite water purification unit (activated sludge tank, sedimentation tanks, and heating tank); (*ii*) a centrifugal pump for water circulation; (*iii*) an air compressor for aerating the activated sludge tank and the fish tanks; and (*iv*) an oil-fueled water heating system, including thermostats and the system's tubing (Fig. 2).

The effluent water from the fish tanks (D) is first taken into the activated sludge tank (Tank A). There it is forcefully aerated, and through activity of aerobic micro-organisms there is considerable decomposition of the protein-containing sludge particles in the waste water. Nitrification, *ie*, the oxidation of nitrogenous excrements and feed residues to ammonium nitrogen and to nitrite and then to nitrate, is brought about by nitrifying bacteria. The bulk of the micro-organisms represents the so-called activated sludge, which flows from Tank A into Tank B, the sedimentation tank. No aeration takes place in Tank B and the sludge sinks to the bottom by gravity. Denitrification takes

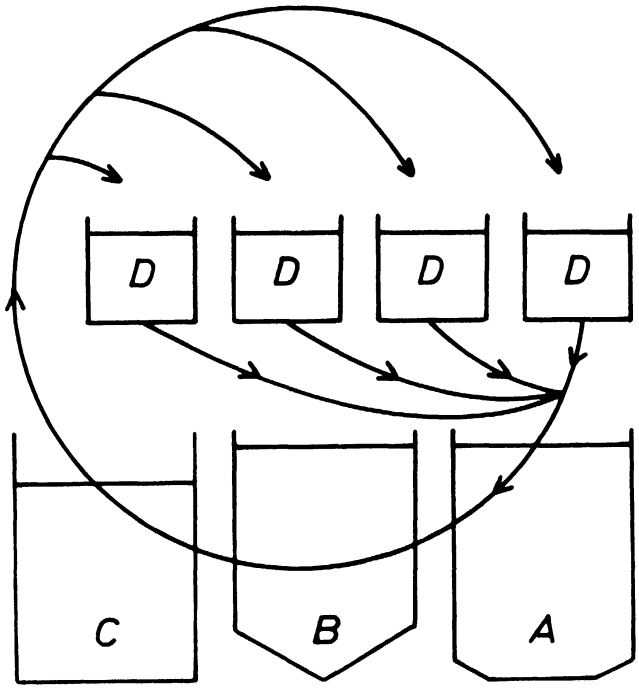


Fig 1 Scheme of the water flow in the circuit from fish tanks (D); through activated sludge tank (A), sedimentation tank (B), and heating and pumping tank (C), back to the fish tanks (D)

place here by which the nitrogen is set free in atomic form and the gas can escape. The water purified now flows over from the surface into Tank C, the heating and pumping tank.

As the sludge sinks to the bottom of Tank B and the water rises, a certain amount of water purification takes place. The sludge deposited on the bottom of the sedimentation tank is constantly pumped back into the activated sludge Tank A by air pumps. The sludge level in the sedimentation tank is continually measured, since by increase of the activated sludge mass, the sludge level in the sedimentation tank also rises. it may then happen that sludge will overflow into the heating and pumping tank, which causes turbidity of the circulating water. In order to avoid this, the sludge should be pumped off occasionally so that it does not exceed a certain level.

The water losses that occur in the circulating system, through evaporation and by pumping off the sludge, are automatically compensated for in Tank C by water from a well which is connected with the tank by a float valve. A meter controls the quantity of incoming fresh water which each day amounts on the average to 1–2% of the total quantity of water in the system. In heating and pumping Tank C, the water is kept at a constant temperature (controlled by a thermostat) by a heating plate connected with the central heating system. A centrifugal pump installed in the engine room sucks the cleaned water out of the heating and pumping tank and pumps it back into the fish tank through a pressure pipe. The cycle is thus closed (Fig. 3).

As already mentioned, nitrifying processes take place in the activated sludge tank under aerobic conditions, and denitrifying processes take place in the non-aerated sedimentation tank, presumably in the almost anaerobic zones on the bottom, and also inside the individual flakes of sludge. More than ten years' practical experience has shown that, by the antagonistic processes of nitrification and denitrification and the renewal of fresh water supply to substitute for water losses, the toxic values are not exceeded with respect to ammonium nitrogen, nitrite or nitrate. Nitrate values of 1 000 mg/l and more, which occasionally occur, have, thus far, not shown any negative effects on the

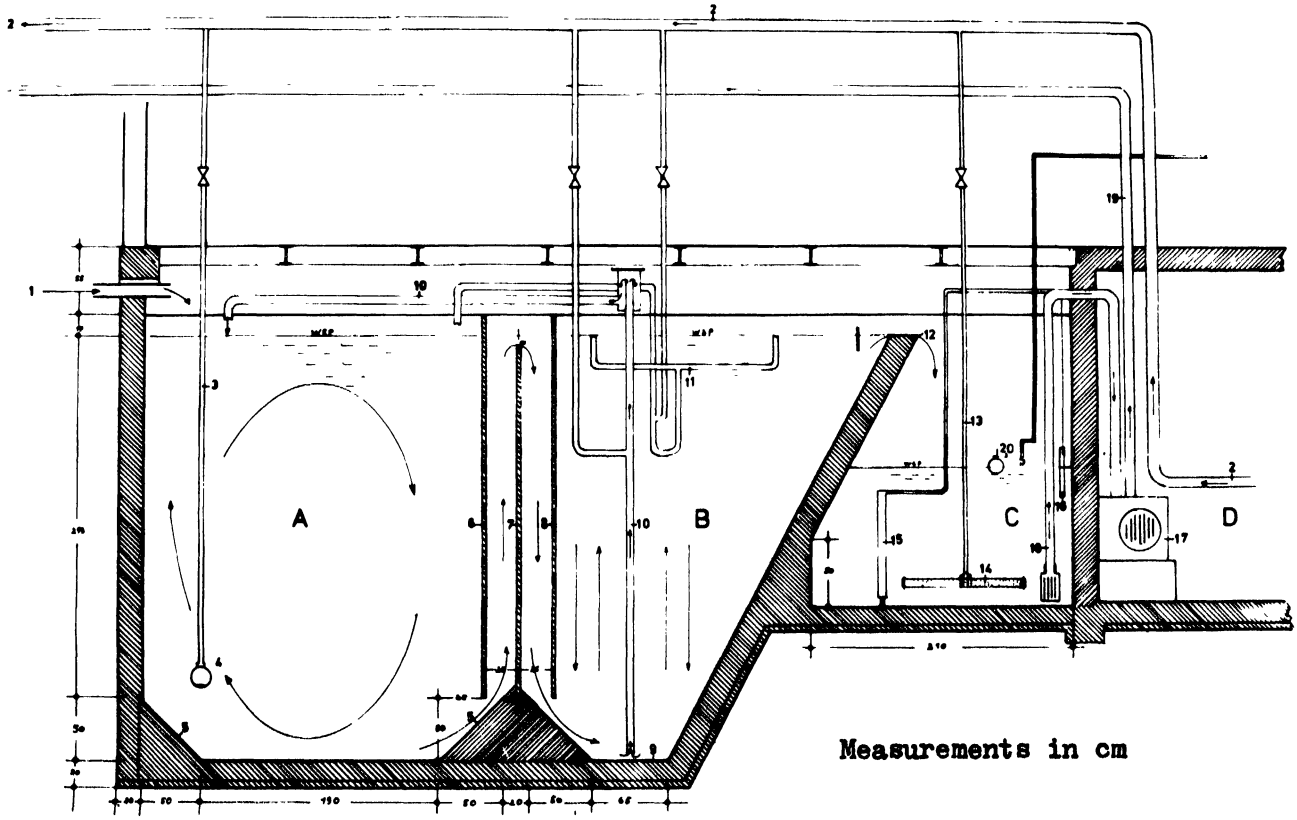


Fig 2. Sectional view of one of the Ahrensburg purification units with a capacity of about 50 m³



Fig 3. View of the purification room with six separate water circuits, each with a capacity of about 50 m^3

development of weight in common carp (*Cyprinus carpio*), grass carp (*Ctenopharyngodon idella*) and European catfish or wels (*Silurus glanis*). However, in order to offer optimal environmental conditions to more sensitive fish species, the tripartite purification unit can be complemented by another tank. This denitrification tank serves especially for nitrate elimination. It is not aerated but the sludge must be stirred by means of a slow-moving stirrer to avoid decomposition (Meske and Nägel, 1975; Nägel, Meske and Mudrack, 1976).

3 Loading the system

The stocking density in the fish tanks of this circulating system is very high. The normal stocking density amounts to 1:5, *ie*, 1 kg of fish to a 5 l tank; however, a ratio of 1:2 is possible. Since there is a constant flow of water, the space, *ie*, the size of the tank itself, is not so important (Fig. 4). It has been calculated that for 1 kg of fish a flow of water of 0·3 l/min is required. With respect to the total quantity of water in the circulating system, the load can amount to 1:30, *ie*, for 1 kg of fish, 30 l of water are required. (Compared with this value, the average stocking density in a Central European carp pond amounts to 1:20 000.)



Fig 4. An example of the high stocking density in a fish tank. Each half of the tank (volume 20 l) holds five carp averaging 454 g in weight. (Five months later they had gained an average weight of 918 g)

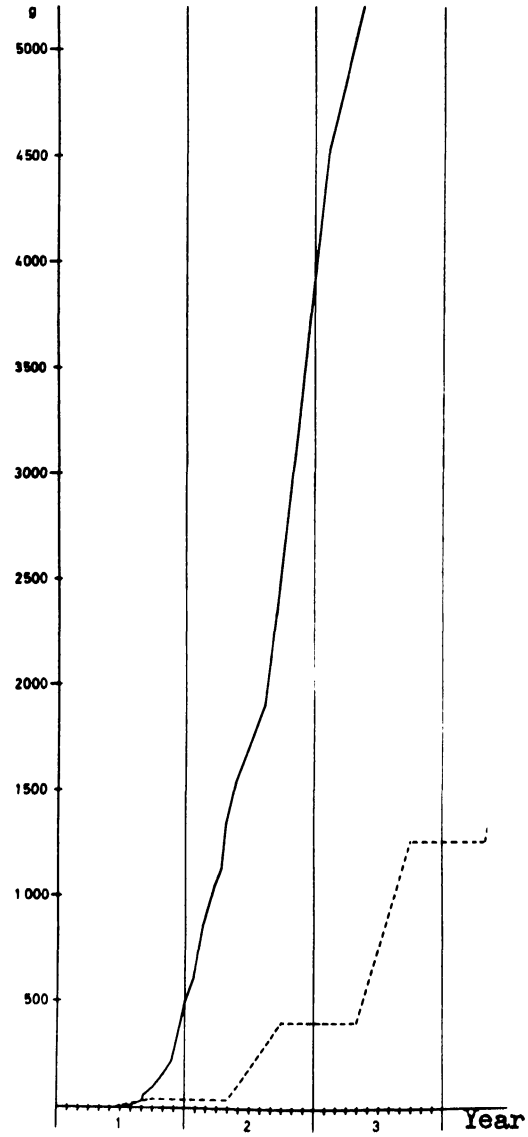


Fig 5. Comparison of the average growth in weight of common carp in Central European ponds (dotted line) with growth values of carp from the warmwater recirculating system (solid line)

Optimum utilization of the production capacity of a circulating system is reached by not exceeding, if possible, the above-mentioned stocking density values. This makes it necessary that the maturing fish are moved as often as possible to a larger tank.

Thus, by respective technical installations, constant optimal utilization of the system and continuous fish production are obtained. The environmental conditions are controllable and adjustable. By paralleling all fish tanks of a circulating system, identical environmental conditions are guaranteed for each tank. The temperature can be kept constant and the fish can be fed the whole year round; this ensures a constant growth throughout the year (Fig. 5).

4 Results and possibilities

At a constant water temperature of 23°C, a common carp thus grows from the time it is hatched to 1·5–2·5 kg within a year. Cessation of growth during winter, as happens in ponds of Central Europe, does not occur. Similar weight increases have been obtained in grass carp and European

catfish. Feeding is carried out throughout the year with feed in either granulated or pelleted form. It is normally composed of fishmeal containing commercial mixed trout feed.

Holding fish in this manner permits tests of the effect of various abiotic and biotic parameters, including problems of physiology of fish nutrition. Such a closed water system can also be used when carrying out experiments on the development of new diets for fish. For example, a fishmeal-free feed, substituting dairy products as a protein source, was developed and tested on common carp and grass carp (Meske, Ney and Pruss, 1976). Tests have also been

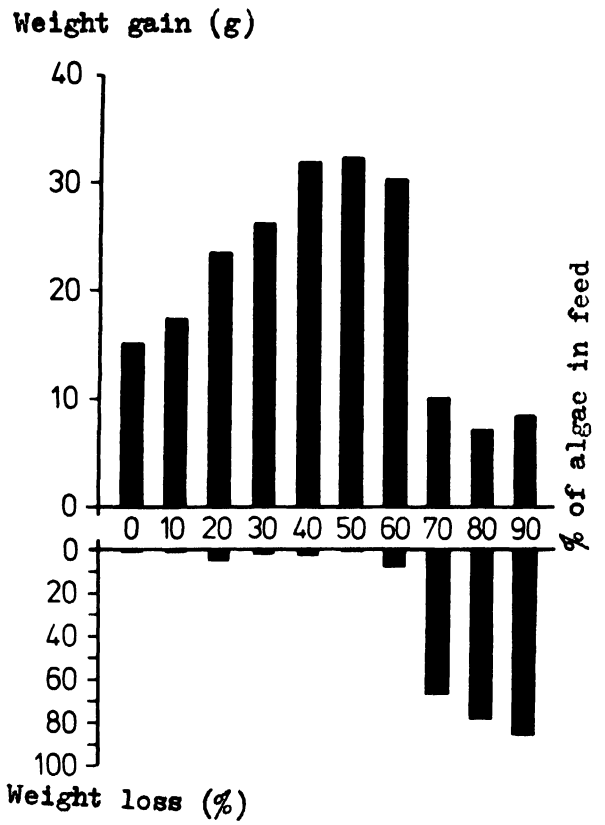


Fig 6. Results of a test with common carp on the effect of green algae as an additive to a fishmeal-free basic feed. The growth and losses of carp with increasing share of algae in the feed are shown

conducted with this recirculating system using the unicellular green alga (*Scenedesmus obliquus*) as a food additive (Meske and Pruss, 1976). It was shown that an accelerated growth rate in carp can be obtained by increasing the amount of algae in the feed. It was only when the algal content amounted to over 50% that deficiency symptoms and loss in weight occurred (Fig. 6). A mixture of 68% fishmeal-free basic feed and 32% of green algae was compared with three manufactured feeds containing fishmeal. Fig. 7 shows that this fishmeal-free feed mixture (feed A) is at least as good as the usual feeds (B, C, D) tested. Analysis of carp fed with fishmeal-free feed showed that the flesh had an extremely low fat content (1·6% of fat) with a high protein content (19·6%) (Reimers and Meske, 1976).

Apart from the development of feeds, retention of fish in a circulating system can also serve the study of reproductive biology. If kept throughout the year in water of 23°C, common carp will become mature after about one year. Their reproduction is not dependent on a seasonal rhythm, and the fish can spawn several times a year.

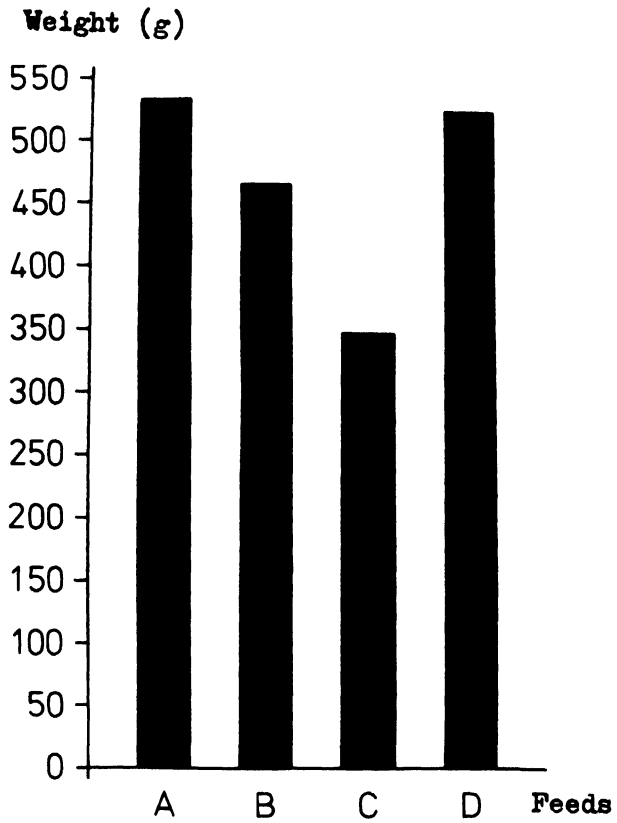


Fig 7. Tests of a fishmeal-free food mixture containing algae (A) and three conventional fishmeal containing feeds (B, C, D). The average weight per carp after a test of 26 weeks is shown

Controlled reproduction is obtained by hypophysation and by artificial incubation of the eggs in zuger jars. The development of standard preparations for controlled artificial reproduction is in progress.

Practical application of the described circulating system for fish production requires a cost-profit analysis which should be adapted to existing conditions. Important factors in this are the: (*i*) current prices of feeds, (*ii*) current prices for edible fish from open waters, (*iii*) current energy costs, and (*iv*) species and age of fish to be produced.

5 Acknowledgements

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Chapter VIII Artificial Recruitment and Transplantations

Improvement of Fishery Resources in Inland Waters Through Stocking

V. G. Jhingran and A. V. Natarajan

Abstract

Some of the reasons for stocking inland waters (other than fish ponds) are listed. These include the need to replace or augment stocks decimated by: decline of water quality (*eg*, by pollution); barriers to migration to spawning grounds (in the case of anadromous fishes); and overfishing. New stocks may also be transplanted to areas where they are not indigenous. These may be waters barren of fish or waters where it is felt that the exotic fishes will be useful for food, sport or forage or as a control of undesired species.

The general practices and success of stocking fish in rivers, lakes, reservoirs and some brackishwater lagoons are reviewed with respect to certain waters in North America, South America, the USSR, Europe, Asia, Africa, Australia and New Zealand.

Some of the principles concerning stocking are reviewed, it being concluded that: (*i*) many transplants have been useful and some harmful; (*ii*) the practice of continuous stockings of fry and fingerlings differs decidedly in various parts of the world, being carried on, for example, rather massively in the USSR and much less so in North America where study has shown a very low rate of return of stocked fingerling salmonids in streams, albeit, a better one in small lakes; (*iii*) under conditions of affluence where sport fishing is important, the planting of sport fish is practised; (*iv*) the stocking of certain anadromous salmonids can be economically successful provided they are properly reared and properly planted; (*v*) stocking in waters containing resident fish is not a simple matter and its success should be carefully appraised before continuing stocking.

Amélioration des ressources halieutiques des eaux intérieures par empoissonnement

Résumé

On signale certaines des raisons qui militent en faveur de l'empoissonnement des eaux intérieures (autres que les étangs piscicoles), notamment la nécessite de remplacer ou d'augmenter les stocks décimés par la détérioration de la qualité de l'eau (du fait de la pollution, par exemple), par les obstacles aux déplacements vers les aires de reproduction (pour les poissons anadromes) et par la surpêche. On peut aussi transplanter de nouveaux stocks dans des zones dont ils ne sont pas originaires: il peut s'agir d'eaux dépourvues de poisson ou encore d'eaux dans lesquelles on estime que les espèces exotiques pourront être utiles pour l'alimentation humaine, pour la pêche sportive ou pour la nourriture d'autres poissons ou bien pour combattre des espèces indésirables.

On passe en revue les méthodes généralement pratiquées pour le repeuplement des cours d'eau, des lacs, des réservoirs et de certaines lagunes d'eaux saumâtres et l'on décrit les résultats obtenus en Amérique du Nord et du Sud, en URSS, en Europe, en Asie, en Afrique, en Australie et en Nouvelle-Zélande.

Certains principes applicables en matière d'empoissonnement sont examinés et l'on en conclut que: (*i*) nombre de transplantations ont été utiles et certaines nuisibles; (*ii*) les pratiques de repeuplement continu en alevins varient beaucoup selon la partie du monde: empoissonnements massifs en URSS et bien moins considérables en Amérique du Nord où l'on a constaté un rendement extrêmement faible du stockage des alevins de salmonidés dans les fleuves et légèrement meilleur dans les petits lacs; (*iii*) dans les régions nanties où la pêche sportive est importante, on pratique la mise en eau d'espèces interessant la pêche sportive; (*iv*) l'empoissonnement avec certains salmonidés anadromes peut être économiquement rentable à condition qu'ils soient élevés et implantés dans des conditions correctes; (*v*) l'empoissonnement des eaux déjà peuplées n'est pas simple et il faudrait réaliser des évaluations minutieuses avant de continuer à empoissonner.

Mejora de los recursos pesqueros de las aguas continentales mediante repoblación

Extracto

Se indican algunas de las razones por las que se procede a la repoblación de las aguas continentales (sin contar los estanques piscícolas); entre ellas, la necesidad de sustituir o aumentar las poblaciones diezmadas por el empeoramiento de la calidad del agua (por ejemplo, debido a la contaminación), las barreras que se oponen a los movimientos migratorios hacia los frezaderos (en el caso de los peces anádromos) y la sobrepesca. También se pueden trasplantar nuevas poblaciones a zonas de las que no son nativas. En ese caso, puede tratarse bien de aguas totalmente desprovistas de peces o de aguas en las que se cree que la introducción de especies será útil para la alimentación, para la pesca deportiva, como alimento para las especies ya existentes, o para controlar especies indeseables.

Se examinan los métodos generales y los resultados de la repoblación de ríos, lagos, embalses y algunas lagunas salobres costeras, citando casos de América del Norte, América del Sur, la URSS, Europa, Asia, Africa, Australia y Nueva Zelandia.

Se examinan algunos de los principios de la repoblacion, llegando a la conclusión de que: (*i*) muchos trasplantes han sido útiles y algunos perjudiciales; (*ii*) en la siembra de alevines y jaramugos con carácter continuo se encuentran claras diferencias entre diversas partes del mundo: se realiza masivamente, por ejemplo, en la URSS, y con mucha menor intensidad en América del Norte, donde los estudios hechos han revelado un bajísimo índice de retorno de los alevines de salmónidos sembrados en cursos de agua, aunque en el caso de la siembra en lagos pequeños se han obtenido mejores resultados; (*iii*) bajo condiciones de afluencia, en donde la pesca deportiva es importante, se practica la siembra de peces deportivos; (*iv*) la siembra de determinados salmónidos anádromos puede ser económicamente fructífera a condicion de que se crien y siembren adecuadamente; (*v*) la siembra en aguas ya habitadas no es una cuestión sencilla, y es preciso evaluar atentamente los resultados antes de proseguir la repoblación.

1 Introduction

Rivers, lakes and reservoirs form an important component of the globe's freshwater resources. About 3% of the water on earth, which includes glaciers, is fresh (Isayev, 1971). The immense inland waters (including estuaries and lagoons) support an ichthyofaunal wealth of considerable importance providing valuable fisheries useful as a source of food and also for recreation. Some of these fish are resident species, others undertake different degrees of migration; all of them are highly susceptible to the influence of man upon their aquatic environment.

As civilization progresses, industries mushroom, agriculture expands, power needs increase and problems of water conservation and management which affect these fisheries are compounded. Pollution of both organic and inorganic origin, together with harmful forms of water development, interfere with the requirements of aquatic organisms for food, reproduction and living space. Overfishing is also a cause of decline in fish stocks.

Dams cause physical obstructions to valuable anadromous fish species, such as salmon, shad and sturgeon, preventing them from reaching spawning grounds and interfering with downstream migration. Eels face a similar problem in reverse. Fishways sometimes appear to hinder not help the ascent of fish, and devices designed to assist downstream movement of young are not always successful either. Artificial propagation through the release of hatchery-reared fingerlings or fish of larger size is, in many cases, an invaluable method of preserving these stocks to ensure sustained fisheries.

Stocking also has an important role in the development of fisheries in reservoirs. In many cases only initial stocking is required, but there are also a large number of cases where there is limited spawning habitat for prime species, and it may also be useful to fill vacant ecological niches. Many lagoons in the Mediterranean area have registered significant increases in fish yield as a result of intensive stocking.

Similar results have been achieved in many waters in the Far East.

Stocking is a powerful tool in stock manipulation and larger harvests can often be realized by selectively stocking fishes that utilize the lower segments of the food chain. Transplantation is another important management tool in the improvement of fishery resources in inland waters. It is practised on a massive scale in the USSR. In India, many of the major carps have been transplanted from rivers of the Northern Plain to those in Peninsular India with considerable success. North America has been an especially fertile field for such transplants although some, such as the introduction of the common carp, have received little approval.

The stocking practices and policies adhered to in different countries are examined in this review.

2 Stocking practices in different countries

2.1 *North America*

2.1.1. *USA*. Stocking practices in the United States have been modified considerably within the last few decades. At one time, fish culturists there, and in Canada, experimented with the propagation of many food and sport fishes, thinking that this was the key to maintenance of stocks. Most of these programmes have long since been discontinued following investigations which showed that, although initial introductions of a species were often successful, maintenance stocking using fry or small fingerlings was all too often a failure. For example, the introduction of shad (*Alosa sapidissima*) from the Atlantic to the Pacific seaboard firmly established this species in a new habitat. Many years of stocking shad in its native east coast streams has produced no evidence of increase in its population.

There has been an overall tendency to: (*i*) be much more discriminate in the choice of fish to be planted (thus lessening the waste of fish in unsuitable waters as well as the danger of unsuitable introductions); (*ii*) eliminate much of the former planting of fry and fingerlings in waters where returns have been found to be negligible; (*iii*) rely much more on natural propagation (coupled with greater restrictions on fishing) to maintain stocks in many waters, especially streams; (*iv*) cultivate sources of broodstock rather than obtain eggs or young from wild sources.

Conversely, there is continued progress toward: (*i*) production of much better stocking material (especially with respect to salmonid stocks) in the sense that the fish to be stocked are genetically adapted to their environment, nourished adequately, and free from disease; (*ii*) in the case of anadromous salmonids (whether stocked for food or sport), rearing to larger size and release at the times and places where seaward migration will be facilitated; and (*iii*) in the case of trout sport fisheries, rearing to catchable size for quick catch in areas of heavy fishing intensity.

In warmwater lakes and reservoirs largely devoted to sport fishing, the general policy for about thirty years has been to rely on only initial stocking of a wanted species or to depend upon the original fauna to provide the harvest. This practice was, however, often supplemented by initial stocking with forage fish, as well as with predaceous fish to fill vacant ecological niches, reduce the numbers of unwanted species or to furnish a particular type of fishing. There is now, however, in a few areas with very high fishing intensity, thought of a partial revival of the policy of continuous stocking even of predaceous sport fish such as largemouth black bass (*Micropterus salmoides*). Stocking policies are, therefore, in a certain state of flux, but in any case the practices are generally based on scientific investigation of the actual returns to either commercial fishermen or anglers.

Trout stocking for sport dominates the stocking programme by both the state and federally-operated hatcheries. Circa 1974 these agencies stocked more than 100 million fingerling trout and about 70 million large (25 cm) trout, so called 'catchables'.

Production of chinook (*Oncorhynchus tshawytscha*) and coho (*O. kisutch*) Pacific salmon, and steelhead trout (*Salmo gairdneri*) is a major programme in the western USA with over 320 million of these salmonids produced yearly. The salmon are utilized, of course, primarily as commercial fish but also as sport fish. Atlantic salmon (*Salmo salar*) are being stocked on the east coast to try to rebuild the debilitated American fishery for this species; about a quarter million smolts are produced yearly.

Finally, with respect to warmwater species, the annual production for stocking (again circa 1974) totals about 100 million fish of which about three quarters are bluegills (*Lepomis macrochirus*), largemouth bass (*Micropterus salmoides*) and channel catfish (*Ictalurus lacustris*). The other one quarter is composed largely of striped bass (*Morone saxatilis*), walleyes (*Stizostedion vitreum*), pike (*Esox lucius*) and some muskellunge (*Esox masquinongy*) (see Anon., 1974).

The management of lakes in the United States includes such aspects as chemical treatment to remove undesirable species, provision of cover, and stocking. Stocking there is now undertaken largely for the benefit of sport fisheries, although in the past commercial fishing was considered, especially in the Great Lakes. Stocking with coldwater species includes primarily salmonids, such as rainbow trout (*Salmo gairdneri*), brown trout (*Salmo trutta*), some landlocked salmon (*Salmo salar*) and the chars, brooktrout (*Salvelinus fontinalis*) and lake trout (*S. namaycush*) and two Pacific salmon, the landlocked kokanee (*Oncorhynchus nerka*) and the coho (*O. kisutch*). In waters less suitable for salmonids, various species (some called coolwater fish) like black basses (*Micropterus*), white perch (*Morone americana*), and pike-perches (*Stizostedion*) are considered for stocking.

In warm waters, largemouth black bass (*Micropterus salmoides*), bluegill (*Lepomis macrochirus*), and other sunfishes, crappies (*Pomoxis* spp.) and catfish (*Ictalurus*) are stocked.

Many high mountain lakes in California and other western states are characterized by being unfavourable for spawning and, in these instances, are often stocked regularly, especially with brook or rainbow trout.

The Great Lakes, which constitute an important area for freshwater commercial fisheries, were once intensively stocked with whitefish (*Coregonus clupeaformis*) and walleye (*Stizostedion*). However, an early analysis of data on stocking of whitefish in relation to yield did not show any positive correlation in Lake Erie (Van Oosten, 1942). Similar stocking efforts in the case of yellow pike-perch (*Stizostedion vitreum*) in Lakes Huron and Michigan (Hile, 1937) and in the Lake of the Woods, Minnesota (Carlander, 1945) were similarly unsuccessful. Competition with resident species and poor viability of the hatchery-reared fry could have been, among other factors,

responsible for unfruitful stocking. In recent years, the Great Lakes have also been stocked with lake trout. The failure of lake trout has been attributed to the parasitic sea lamprey (*Petromyzon marinus*), which gained access to these lakes after construction in 1932 of the Welland Canal. The introduction of coho salmon (*Oncorhynchus kisutch*) in Lake Michigan as a predator on alewife (*Alosa pseudoharengus*), which invaded Lake Michigan in the same manner as the sea lamprey, marked a new chapter in the stocking history of the Great Lakes (Smith, 1968). The coho has seemingly brought under control an explosive population growth of alewife. In the wake of successful stocking of coho, chinook salmon (*Oncorhynchus tshawytscha*) were also introduced in Lakes Michigan and Superior as a predator of alewife (Smith, 1968).

The policy for stocking streams in the USA has somewhat similar objectives to that of lakes, namely development or maintenance of sport fisheries. Deforestation, erosion and other results of man's activity here have seriously impeded natural reproduction in many trout streams necessitating stocking on a continuing basis. Generally speaking, the survival of stocked fry or fingerling trout in streams is extremely low. Consequently, an effective but costly programme of stocking catchable trout ('put and take fishing') has been developed in many heavily fished waters.

Rivers assume enormous importance as pathways of anadromous fishes, and Pacific salmon (*Oncorhynchus*) form important commercial fisheries in the USA and Canada. These salmon catches have dwindled during the last few decades in great part because of dams, abstraction of water, other destruction of habitat and pollution. In addition, the expansion of high-seas fishing has resulted in the overfishing of the same stocks by the operating fleets of the USA, Japan, the USSR and Canada. Against this background large-scale stocking of smolts seems inevitable if the valuable stocks are to be preserved. Fortunately the technology of hatchery propagation is well developed in the USA and other countries where Pacific salmon have natural distribution. In the USA the hatchery propagation of Pacific salmon includes chinook salmon, coho salmon, chum salmon (*Oncorhynchus keta*) and pink salmon (*O. gorbuscha*). Hatcheries in California, Oregon and Washington annually release about 200 million chinook and coho salmon (Bardach, Ryther and McLarney, 1972). The impact on the fishery by stocking smolts is reflected by the fact that in 1965 22% of the chinook salmon catch of the commercial Columbia River fishery and 15% of its sport-fishing catch was a result of stocking.

Estimates for 1967 indicate that hatcheries provided 15·7 million pounds (7·1 million kg) of salmon and steelhead trout (*Salmo gairdneri*) to this fishery (Glude, 1971). Similarly, coho salmon stocking has resulted in increased yield (Bardach, Ryther and McLarney, 1972).

Reservoirs are now one of the important inland water resources in the USA. They total in excess of 3·5 million ha in area and projections indicate that they will total 4·6 million ha in area by 1976 (Stanberry, 1967).

In coldwater impoundments, rainbow trout, brown trout, lake trout and other salmonids are stocked. Most reservoirs in the USA are, however, of a warmwater or coolwater type. Many southeastern reservoirs contain gizzard shad (*Dorosoma cepedianum*) which often provide a forage base for the development of sport fisheries. In these reservoirs bluegill (*Lepomis macrochirus*), white crappie (*Pomoxis annularis*), black crappie (*P. nigromaculatus*), largemouth bass (*Micropterus salmoides*), smallmouth bass (*M. dolomieu*) and spotted bass (*M. punctulatus*) often occur naturally. Continual stocking of such fish is rarely practised as natural propagation usually suffices. Some selective stocking of other fish is done in some reservoirs, *eg*, white bass (*Morone chrysops*), walleye (*Stizostedion vitreum*), rainbow trout, muskellunge (*Esox masquinongy*). In order to serve the need of a small forage fish, the threadfin shad (*Dorosoma petenense*) has been introduced into many southeastern and western irrigation and power reservoirs so that it can be utilized by all sizes of predator fish (Parsons and Kimsey, 1954). The threadfin shad as well as gizzard shad also utilize plankton and detritus effectively (Baker and Schmitz, 1971). Striped bass (*Morone saxatilis*) are also stocked in reservoirs to boost sport fishing and control gizzard shad.

Another form of stocking often practised now is planting trout (usually rainbow) to occupy the coldwater portion (the 'lower storey') of a reservoir while the warmer 'top storey' is occupied by warmwater species.

2.1.2 *Canada.* The sockeye salmon (*Oncorhynchus nerka*) occupies an important place in Canada and is a dominant species in the Fraser River of British Columbia. It prefers rivers that have lakes which form the nursery grounds. Sockeye, in common with other Pacific salmons, are confronted with overfishing and river obstructions and need stocking support.

In Canada, propagation of sockeye is largely carried out through artificial spawning channels. The hatchery rearing and stocking is largely confined to chum salmon (*O. keta*) and pink salmon (*O. gorbuscha*). Canada and the USA together produce 100 million fry of these two species for stocking (Bardach, Ryther and McLarney, 1972).

From a stocking point of view, special mention has to be made of the Salmon Enhancement Programme of the Pacific Biological Station of the Fisheries and Marine Service, Environment Canada, Nanaimo, British Columbia. This programme seeks to develop new, and improve existing, ways of increasing production of Pacific salmon by: (*a*) improving efficiency and reducing costs of hatchery rearing of coho; (*b*) developing a new technique of incubating salmon eggs in gravel-filled boxes that greatly increases fry survival; (*c*) increasing stream production of coho and chinook salmon; (*d*) increasing efficiency of spawning channels; and (*e*) establishing salmon runs by transplants to streams having small runs or no runs.

The pink salmon accidentally introduced in the Canadian waters of Lake Superior in 1956 has successfully adapted to the new environment and is developing into a fishery of commercial importance (Bardach, Ryther and McLarney, 1972).

Fry of the white fish (*Coregonus clupeaformis*) were stocked nearly every year between 1882 and 1954 in the Canadian waters of Lake Ontario. In some years, the level of stocking was as high as 208 million. However, analyses of stocking and yield during 1927–54 did not show any definite correlation (Lapworth, 1956; Christie, 1963). General ecological adaptability could not be a reason as the fish is indigenous to the Great Lakes and forms a commercial fishery in Lake Ontario, but viability of hatchery-reared fry, their size, place of release and subsequent predation are possible factors rendering the stocking ineffective.

The brook trout is one of the principal native sport fish in the fresh waters of the Canadian maritime provinces and has been stocked in lakes and streams in an effort to augment the supply for sport fishing. The lake trout (brown trout), rainbow trout, smallmouth bass, and largemouth bass, are also stocked in Canada to serve the same purpose.

There are a large number of small, shallow, unproductive lakes in Manitoba and Saskatchewan in which it may be difficult for fish to overwinter. In recent years, some of these have been stocked in spring with the fry of rainbow trout which have been harvested as food fish in the autumn (Bardach, Ryther and McLarney, 1972).

2.2 *South America*

2.2.1 *Brazil.* Members of the family Characidae (*Curimatus, Leporinus, Prochilodus* and *Triportheus*) are bred and stocked in reservoirs in the northeastern part of the country. These characins include both herbivores and carnivores. In addition, carnivorous cichlids (*Astronotus ocellatus, Cichla ocellaris* and *C. temensis*) and sciaenids (*Plagioscion surinamensis* and *P. squamosissimus*) are bred and stocked in reservoirs (Bardach, Ryther and McLarney, 1972; Acero. Sánchez, 1974).

2.2.2 *Peru.* The pirarucu (*Arapaima gigas*), the gigantic freshwater fish, is bred and stocked in the upstream stretches of the River Amazon. The impact of these measures on the stock and yield is not known.

2.2.3 *Chile.* The pejerrey, *Odonthestes basilichthys* (Atherinadae), was introduced to Chile from Argentina. It is bred and stocked in lakes.

2.3 *USSR.*

The USSR has a very rich freshwater resource in the form of rivers with an estimated length of 500 000 km and 30 million ha of lakes (Isayev, 1971). In addition, a large number of reservoirs (with an estimated surface area of 6 million ha) have been formed as sources of hydro-electric power and for other purposes on the Volga, Don, Donets, Dniestar, Western Dvina, Neman, Kura, Ob, Yenisey, Lena and in the river basins in the northwest, the Caucasus and Soviet Central Asia (Lepitzky, 1965; Isayev, 1971).

Dams, pollution, logging, and overfishing inevitably have had a deleterious effect on the anadromous fishes, such as sturgeons, salmon, and some cyprinids—necessitating hatchery propagation and stocking.

The international fishing in Norwegian waters and in the Baltic has adversely affected the Atlantic salmon (*Salmo salar*) in the northern European spawning streams of Soviet waters. Hatcheries located in the Baltic, White and Barents Sea basins release annually more than 2 million young Atlantic salmon to provide support to the dwindling fishery (Isayev, 1972). In addition to this stocking, annual stocking of pink salmon (*Oncorhynchus gorbuscha*) and chum salmon (*O. keta*) in the USSR exceeds 30 million fish. Chum and pink salmon populations transplanted from Pacific waters (Sakhalin Island) to European waters of the USSR (Barents and White Seas) have become fully established. Pink salmon now occur, not only in Barents Sea catches, but also in the fisheries of neighbouring countries. They have been found in Finland, Norway, Iceland and the UK (Bardach, Ryther and McLarney, 1972).

The so-called Caspian 'salmon' (*Salmo trutta caspius*), which needs upstream stretches for spawning, dwindled into an insignificant fishery on account of power projects on the Samur and Kura Rivers. As attempts at hatchery propagation for Caspian salmon have not been successful, the chum salmon (*O. keta*), which spawns in the lower reaches of rivers, was stocked in the Caspian Sea. During the period 1962–65, 5 850 000 fry of chum salmon were released. The fish has established itself and breeding runs have been observed in the Samur River (Magomedov, 1970).

Various whitefishes (*Coregonus* spp.), native to the northern waters of the USSR, are another group of fishes which are affected by dams in their spawning migrations and may require stocking support. The European cisco (*Coregonus albula*), the whitefish (*C. lavaretus*) and peled (*C. peled*) have been extensively transplanted into new waters (Karpevich and Lukonina, 1968, 1971 and 1972).

Hydro-electric dams, especially on the Black, Caspian and Aral sea basins, pose threats to migratory stocks of cyprinids like roach (*Rutilus rutilus*), bream (*Abramis brama*), vimba (*Vimba vimba*) and shemoia (*Chalcalburnus chalcoides*) (Bardach, Ryther and McLarney, 1972). As many as 3 358 million young roach and 762 million young bream were released in 1954 to replenish natural stocks (Ovchynnyk, 1963).

With the damming of the Volga and other rivers of the Caspian Basin, the stocking of young fish running into the millions has become necessary in the case of Caspian sturgeons: beluga (*Huso huso*), spiny sturgeon (*Acipenser nudiventris*), sturgeon (*A. guldenstadti*) and sevryuga (*A. stellatus*) (Lageza, 1971). Sturgeons also form fisheries in the basins of the Black Sea, the Sea of Azov and the Aral Sea. In 1965, 52 million young fish were stocked to enhance sturgeon stocks (Bardach, Ryther and McLarney, 1972).

There has been a continuing effort in the USSR to improve fish production in reservoirs. Reservoirs on the Don, Volga, and other rivers in the European part of the USSR are stocked with bream, common carp (*Cyprinus carpio*), whitefish (*Coregonus lavaretus*), and pike-perch (*Stizostedion lucioperca*). In addition, southern reservoirs are also stocked with silver carp (*Hypophthalmichthys molitrix*) for effective utilization of plankton (Lepitzky, 1965; Pirozhnikov, 1968; Jhingran, 1965).

In coldwater reservoirs (*eg*, Novosibirsk, Irkutsk and Bratsk) stocking material includes Baikal cisco (*Coregonus autumnalis migratorius*), *C. nasus, C. peled*, grayling (*Thymallus arcticus*), carp-bream, and pike-perch. The Siberian Fisheries Institute proposes rearing and release of sturgeon fry and introduction of zope (*Abramis ballerus*) (Pirozhnikov, 1968). In many instances, like the Irkutsk reservoir, the carp-bream and common carp were not able to establish themselves, largely because of the very cold water. Reservoirs in Eastern Kazakhstan are intensively stocked with common carp (Fedotova, 1971). The USSR has also initiated measures to acclimatize grass carp (*Ctenopharyngodon idella*) from eastern Asia, to assist in the control of algae and higher aquatic plants in those reservoirs receiving heated water from thermal power plants (Frey, 1967).

Taking into consideration its geographical extent, from Europe through Central Asia to the Far East, and its climatological variations, the USSR has implemented a

vigorous transplantation programme[1]. Fishes involved in these transplantations include sturgeons, salmon, trout, coregonids, smelts (Osmeridae), pickerels (Escidae), carps (Cyprinidae) and perches (Percidae) (Karpevich and Lukonina, 1968, 1971 and 1972). Such introductions largely involve lakes, followed by reservoirs and rivers. The stocking is of the order of 300–400 million fish each year in the form of eggs, larvae, fingerlings and adults. Species obtained from abroad in recent years for commercial rearing and acclimatization in the USSR include European eel (*Anguilla anguilla*), striped bass (*Morone saxatilis*), the ayu (*Plecoglossus altivelis*) and various trout (Karpevich and Lukonina, 1968).

Transplantations within the USSR involve not only fish but also invertebrates to enrich the biotal complex of inland water aquatic ecosystems. Invertebrate introductions include Polychaeta, Mysidacea, Amphipoda, Copepoda and Decapoda (Karpevich and Lukonina, 1968, 1971 and 1972; Jhingran, 1965).

2.4 *Europe.*

The Atlantic salmon (*Salmo salar*) occupies an important place in the commercial fisheries of Europe and is a highly-valued sport fish[2].

In Norway, where there are about 300 salmon rivers, several hatcheries operate to supplement the natural propagation of salmon.

Hatchery-raised Atlantic salmon smolts are regularly stocked in rivers in Iceland, and a good percentage of them return to support a commercial fishery (Bardach, Ryther and McLarney, 1972).

In spite of dams and other impediments, Atlantic salmon have been saved in Sweden largely due to hatchery propagation. Salmon smolts released in Sweden also contribute to Danish and Finnish fisheries. Grayling (*Thymallus thymallus*) and *Coregonus* spp., which are also affected by dams in Sweden, are now hatchery-propagated and stocked (Bardach, Ryther and McLarney, 1972).

Belgium, Luxemburg, France, Switzerland, the Federal Republic of Germany, and the Netherlands have also been involved in the artificial propagation of salmon in the Rhine basin, but pollution and barriers to migration have made these efforts virtually useless.

Virtually all of the European countries, including those of the British Isles, stock various species of fishes, especially trout, in many of their inland waters. There is now a tendency to stock trout at larger sizes in order to ensure greater survival. For example, in recent years, two-year-old brown trout have been released in Danish estuarine waters for fattening. The fish are caught after a year of free life. Studies show that the fish so stocked remain within a 12 km radius from the place of release.

In waters less suitable for trout, warmwater fish are also used. For example, the inland waters of the Netherlands are stocked with hatchery-reared pike (*Esox lucius*), carp and tench (*Tinca tinca*) primarily for angler use.

The brackishwater lagoons of Mediterranean countries are also stocked in order to produce food fishes. In Italy, 'valli' (modified lagoons) are stocked with grey mullets (*Mugil capito, M. chelo, M. saliens, M. cephalus*) as well as the gilthead (*Sparus auratus*), bass (*Dicentrarchus labrax*) and eels (*Anguilla anguilla*). The annual yield of valli, stocked as above, is of the order of 90–200 kg/ha. In Greece, the Porto-Lago lagoon is stocked with fry of the same mullets, and common carp are stocked in freshwater portions of the lagoon. The Vrana lagoon in Yugoslavia is also stocked with grey mullets.

2.5 *Asia.*

The stocking and transplantations practised in rivers, lakes and reservoirs in the Asian part of the USSR have already been discussed. Here the presentation is limited to stocking practices followed in India, Sri Lanka, Indonesia, and Japan.

2.5.1 *India.* Some of the rivers of Peninsular India do not have large fast-growing carps comparable to Gangetic major carps in North India (Jhingran, 1975). In order to enhance the fishery potential of these rivers, these major carps were introduced. Catla (*Catla catla*) have been successfully established in the River Cauvery and rohu (*Labeo rohita*) and mrigal (*Cirrhinus mrigala*) in the lower stretches of the River Godavari (Jones and Sarojini, 1952; Bhimachar, 1959). There are indications that catla and rohu, which were accidentally transplanted, established themselves in the lower stretches of the River Tapti (Karamchandani and Pisolkar, 1967).

The lakes in the Nilgiris, Shevaroys and Kodaikanal were successfully planted with exotic cyprinids, tench, crucian carp (*Carassius carassius*) and the mirror carp (*Cyprinus carpio specularis*), the latter having a wider distribution in Kashmir, Himachal Pradesh and Kumaon (Uttar Pradesh) (Jones and Sarojini, 1952).

Among indigenous sport fishes, *Barbus* (*Tor*) *putitora* was successfully established in the upland lakes of the Kumaon hills (Raj, 1945). Exotic sport fishes have also been planted in India. The brown trout was successfully established in Kashmir and rainbow trout (*S. gairdneri*) in Nilgiris (Jones and Sarojini, 1952; Jhingran, 1975). A trout fishery of some importance has also been developed in high altitude lakes and reservoirs in Kerala and Tamil Nadu (Sehgal, 1972).

Stocking has assumed great importance in the development of fisheries in Indian reservoirs. India has, at present, an estimated 2 million ha of water under impoundment, and this resource is growing year by year. The development of carp fisheries in reservoirs has been accorded a great importance. Stocking is largely confined to the major carps, catla, mrigal, rohu, and the calbasu (*Labeo calbasu*) and, in impoundments in North India, to minor carps, such as *Cirrhina reba, Labeo bata,* and *Puntius sarana.* In the south, stocking covers a wider range; in addition to Gangetic major carps, it includes some peninsular carps like *Labeo fimbriatus, L. kontius, Cirrhinus cirrhosa, Puntius dubius, P. carnaticus* (Natarajan, 1972). In addition, *Etroplus suratensis,* the gouramy (*Osphronemus goramy*), murrels, some euryhaline fishes like grey mullets (*Mugil*), milkfish (*Chanos chanos*) and tarpon (*Megalops cyprinoides*) are also stocked experimentally. Among the exotic carps, both mirror and scale carp are extensively stocked, but their performance in impoundments is not satisfactory except in Govindsagar reservoir (Himachal Pradesh), where they are established and contribute to a fishery of

[1] A list of informative summaries of introductions since 1957 is made available by the Consultative Committee on Questions of Acclimatization of the Ichthyological Commission of the USSR.

[2] Matters concerning Atlantic salmon in the European waters of the USSR are dealt with in section 2.3.

some magnitude. The exotic silver carp (*Hypophthalmichthys molitrix*) holds great promise for impoundments in India. Silver carp stocked in Kulgarhi reservoir (Madhya Pradesh) reached a size of 4·5 kg in 22 months (Rao and Dwivedi, 1972).

The African cichlid, *Tilapia mossambica*, has been introduced into some of the South Indian reservoirs (Jhingran, 1975). In Vaigai reservoir, this tilapia replaced all the other fishes (including the major carps and indigenous fishes) and formed 99% of the total catch in 1964–65 (Sreenivasan and Sundararajan, 1966). In Amaravathy reservoir this species formed 60% of the annual landings a few years ago (Chacko, 1970). There is no doubt that tilapia has boosted the fishery in the Vaigai (38 kg/ha/year) and Amaravathy (93 kg/ha/year) reservoirs. In Keetham reservoir, a small impoundment in Uttar Pradesh, massive annual stockings of fingerlings resulted in a yield of 530 kg/h/year (Khare, 1964). The average fish yield in Indian reservoirs, however, barring a few exceptions, is low (less than 10 kg/ha) and stocking and proper management is required (Jhingran and Natarajan, 1969; Natarajan, 1972a).

2.5.2 *Sri Lanka.* Rainbow trout have been introduced into the higher colder waters of Sri Lanka as a game fish (Fowke, 1938). *Tilapia mossambica* intensively stocked in impoundments has raised the fish yield twenty-fold (Fernando, 1969).

2.5.3 *Indonesia.* The man-made lake Tjiburuj, in Java, produced a remarkable yield (500–600 kg/ha) following stocking with phytophagous and planktonivorous fishes including *Puntius javanicus, Osteochilus hasselti, Tilapia mossambica, Helostoma temminckii* and common carp.

The introduction of common carp, *Puntius javanicus* and *Trichogaster pectoralis* in a shallow volcanic lake in Rewa Pening, Central Java, had a remarkable impact; fish yield was increased from 5 kg/ha to 150 kg/ha.

The transplantation of exotic species, *Puntius javanicus* and *Trichogaster pectoralis*, in the shallow Lake Tempe (circa 15 000 ha) has raised the yield very appreciably.

Stocking of *Tilapia mossambica* and *Trichogaster* in the shallow Lake Lombotto, Celebes, gave a fish yield (for the above species) of 170 kg/ha/year.

2.5.4 *Japan.* Pink (*Oncorhynchus gorbuscha*) and chum salmon (*O. keta*) fry of the order of 400 million are released annually in Japan, usually in estuarine waters. In Hokkaido, there are approximately 160 chum salmon spawning streams. About 77% of the adult chum salmon run in Hokkaido are the result of hatchery release. This is an interesting case of salmon management based almost entirely on hatchery release. *Oncorhynchus masu* has been established in the landlocked freshwater lake of Biwa as a result of fry stocking.

Dolly Varden trout (*Salvelinus malma*) raised in hatcheries are stocked in Japanese rivers to support a commercial fishery and the ayu (*Plecoglossus altivelis*) is also stocked in many waters.

The pejerrey (*Odonthestes basilichthys*) an atherinid, native to Latin America, has been introduced in Japan where it is propagated artificially and stocked in lakes.

2.6 *Africa.*

Africa has a wealth of natural inland waters: the Nile, Niger, Congo, Zambezi, and many other large rivers; the great Rift Valley lakes (Lake Victoria, 67 679 km^2; Lake Tanganyika, 32 000 km^2; Lake Malawi, 38 600 km^2; Lake Albert, 5 600 km^2, and several very large man-made lakes (Lake Kariba, 5 364 km^2; Lake Volta, 8 500 km^2 and Lake Nasser, 3 000–6 200 km^2) (Worthington, 1966). There is also a vast number of smaller lakes and impoundments. Stocking has an important role to play in Africa in order that a richer harvest be taken from these waters.

Lake Victoria has a low fish catch (circa 14 kg/ha/year), although the expectation is that the Lake could yield up to 40 kg/ha/year without stocking. *Tilapia zillii*, which was introduced to utilize some of the marginal vegetation, has become established and has contributed to the commercial fishery (Hickling, 1961). The Nile perch (*Lates niloticus*), presumably accidentally introduced into Lake Victoria, has adapted successfully and is increasing in numbers and widening its spatial distribution. Both Cichlidae and Mormyridae are forage for Nile perch (Gee, 1969).

Lake Kivu, a Rift Valley lake, once considered to be a biological desert, was later found to be rich in plankton which swarms to the surface at night. The planktophagic clupeoid (*Stolothrissa tanganicae*) has since been introduced into the Lake (Hickling, 1961).

Lake Nakivali, a shallow lake in Uganda, registered a remarkable fishery after the introduction of *Tilapia nilotica*. The fish yield rose to 189 kg/ha/year (Hickling, 1961). The Nile perch (*Lates niloticus*) was also introduced into a number of lakes in Uganda (Gee, 1969).

Dams in Uganda and Kenya are largely stocked with *Tilapia* spp. The lakes and dams in the Central Rift Valley of Tanganyika are stocked with *Tilapia nigra, T. nilotica, T. melanopleura* and *T. pangani*. The fish yield varies from 60 to 250 kg/ha/year. Rural water development dams in Ghana are largely stocked with *Tilapia galilaea, T. nilotica* and *T. zillii* (Hickling, 1961).

The man-made Lake Kariba, completed in 1958, has an area of 4 300 km^2. The fish yield in 1963 was of the order of 3 570 tons, largely of *Labeo* spp. and *Tilapia mossambica*. Fingerling *Tilapia macrochir* were stocked at the rate of about 7 tons per year between 1959 and 1962. The impact of stocking on yield is yet to be known (Harding, 1966). The Lake Tanganyika 'sardine' (*Stolothrissa tanganicae*) has since been stocked in Lake Kariba, to utilize the vacant deepwater ecological niche.

The Delta lakes (lagoons) of Egypt are intensively stocked with *Mugil* spp. and eels. The mullets contribute as much as 18–62 kg/ha. The sole (*Solea vulgaris*) was introduced to Karoun lagoon where it established itself (El Saby, 1951; Bardach, Ryther and McLarney, 1972).

In southern Africa there are no indigenous coldwater sport fish of commercial importance. European brown trout and American rainbow trout, which were introduced, have established themselves to some extent in certain rivers of the Eastern Cape, Natal, Transvaal and Basutoland in South Africa and Rhodesia. Optimal ecological conditions do not exist for spawning and continual restocking with hatchery-produced ova or fingerlings is practised (Hey, 1951). The common carp has been established in Vaal River impoundment in South Africa (Du Plessis and Le Roux, 1965).

2.7 *Australia and New Zealand*

2.7.1 *Australia.* There are no indigenous salmonids in

Australia. Brown trout and rainbow trout, which were introduced into Australia, are now established in many rivers in New South Wales, Victoria and Tasmania and, to a lesser extent, in South Australia and Western Australia (Roughley, 1951). Among other introduced fishes, the Crucian carp, the gold fish (*Carassius auratus*) and the tench have become widely established. The common carp is, however, yet to establish successfully in Australian waters (Bardach, Ryther and McLarney, 1972).

2.7.2 *New Zealand.* Among fishes introduced into New Zealand, brown trout, rainbow trout, chinook salmon, and the Atlantic salmon are now well established (Hefford, 1951). The chinook, first established in a southeastern river, spread to most of the east coast rivers of South Island. Similarly, Atlantic salmon became resident in the Waiau River system on the south coast of South Island. Here they no longer seek sea water and have adjusted to fresh water throughout life.

The introduction and establishment of trout in many New Zealand rivers resulted in the decline of 'white bait' (*Galaxias attenuatus*), the juveniles of which form the favoured forage of trout (Hefford, 1951).

Among other salmonid introductions, the two chars (*S. fontinalis* and *S. namaycush*) and *Oncorhynchus nerka* are established, the last as a stunted lake inhabitant. Other transplanted fishes like the European perch (*Perca fluviatilis*), common carp and tench, are also established in lakes and rivers (Hefford, 1951).

3 Discussion

3.1 *Anadromous fish*

Anadromous fish stocks, especially Pacific and Atlantic salmon, have been seriously affected by the construction of dams on their natal streams, by deterioration of water quality through pollution and improper land and water use, and by overfishing, the last largely due to development of high-sea fishing. Many agreements exist between countries concerning regulation of catches and preservation of salmon stocks, but salmon stocks lean more and more heavily on hatchery propagation and stocking. Millions of fry and smolts are released each year by the USA, Canada, the USSR, Japan and European countries. Though a great deal of progress has been made in the hatchery and rearing technology, there are still constraints in maintaining the stocks on the basis of hatchery propagation. Further research efforts are indicated on optimum growing period, hatchery nutrition, and the time and place of stocking fish so that a target of 15–20% return is realized. There is also further scope to develop new breeds through selection or hybridization so that the salmon fishery could be made profitable through artificial propagation. In this connexion, the finding that young hybrid chinook × chum and chinook × pink salmon are salinity-tolerant merits mention as this may render gradual acclimation to sea water unnecessary (Bardach, Ryther and McLarney, 1972).

Transplants of Pacific salmons have also been successful, *eg,* chum and pink salmon from Pacific waters to European waters. This successful transplantation assumes special significance in the face of dwinding fisheries for Atlantic salmon in European waters. The establishment of chum salmon in the Caspian Sea seems useful in the face of diminishing catches of the native Caspian 'salmon' (*Salmo trutta caspius*). Equally remarkable is the establishment of chinook and Atlantic salmon in New Zealand waters and coho salmon in the Great Lakes of North America.

The USSR has taken steps to rehabilitate by large-scale artificial propagation the stocks of a number of anadromous fishes adversely affected by dams, and similar attempts with such species are indicated elsewhere.

3.2 *Rivers and lakes*

In North America and Europe, most lakes and rivers are now little used for commercial fisheries. In the USA the commercial fishery is largely limited to the Great Lakes and the Mississippi River system. The Great Lakes fisheries are also exploited commercially by Canada. However, the interest in river, lake and reservoir recreational or sport fisheries in both North America and Europe is very high. The anglers' ranks in the USA have so swelled that, in respect of trout, it has led to the expensive policy of 'put and take fishing' in heavily fished waters.

In the USSR, where lakes and rivers are developed for commercial fish production, large-scale transplantations of many species of food fishes continues. In the USSR more than 200 000 tons of fish are caught annually in lakes, rivers and reservoirs (Isayev, 1971).

In India, some of the major riverine carps of the northern plain have been successfully transplanted to Peninsular India, and exotic carps have also been well established. For example, the mirror carp now forms 60–70% of the total catch in the lakes of Kashmir Valley and River Jhelum (Sehgal, 1972).

In Africa, lakes are stocked largely with a number of species of *Tilapia*. The introductions of *Tilapia zillii* in Lake Victoria, *T. nilotica* in Lake Nakivali, and *S. tanganicae* in Lake Kivu, have improved their yields remarkably. Similar increases in yield following stocking have occurred in Asia, especially in Indonesia.

Going by available evidence in Africa and Asia, small and medium lakes in general respond remarkably to stocking, resulting in high yields in the range 100–500 kg/ha. These water bodies, therefore, need priority consideration in stocking schedules.

There are a large number of high altitude lakes in many countries which, on account of barriers, have not been naturally colonized by fish or otherwise remain undeveloped from a fisheries point of view. These can be stocked with coldwater fishes. A large number of small, shallow lakes on the west coast of North Island of New Zealand form potentially valuable fishing water, but remain unstocked (Hefford, 1951). It will be useful to identify such areas in each country so that they can be stocked.

3.3 *Reservoirs*

In the USA, reservoirs which cover an estimated surface water area of 3·6 million ha hold promise for commercial fisheries, but the dominance of sport fishing is generally responsible for lessened commercial fishing in these waters. Stocking in reservoirs is selectively done for certain sport fishes which include salmonids, centrarchids, and serranids, and mass stocking, except sometimes initially and in some waters with trout, is not the rule. Natural reproduction forms the basis of the catch of warmwater fishes here. Since these fishes are high in the food chain, they contribute a comparatively low yield/ha. The average yield in reservoirs in the USA is only 19·5 kg/ha (Stanberry, 1967),

although it has been estimated that a total yield of about 100 kg/ha, could be achieved with fuller exploitation of the complete assemblage of resident fishes.

The USSR, where about 6 million ha are under impoundments, has practised large-scale stocking and transplantation of fish to develop commercial fisheries in its large reservoirs. Yields of the order of 25–45 kg have been achieved in many southern reservoirs (Lepitzky, 1965; Pirozhnikov, 1968; Jhingran, 1965). Those of the northern impoundments have, however, been much lower.

In Africa, medium and small reservoirs are largely stocked with a variety of species of *Tilapia*. Of the huge new impoundments, only Lake Kariba has been intensively stocked and this only during its first years.

In India, where reservoirs cover an estimated 2 million ha, stocking is largely confined to major carps and common carp. *T. mossambica* introduced experimentally in some south Indian reservoirs has done well and has contributed between 35 and 55 kg/ha. But, its introduction is not favoured as competition reduces the production of major carps.

In South America, stocking of reservoirs has been largely confined to that of characids and cichlids as in Brazil. The cyprinids are represented only by the exotic common carp.

Reservoirs now occupy a very important place in the world's inland water resources, and continue to increase in number and area as more and more rivers are harnessed to meet the needs of agriculture, power and industry. Development of fisheries in these water bodies sometimes involves large-scale stocking of prime fishes. Cyprinids, being on the lower end of the food chain, have an increasing part to play in the development of reservoir fisheries in those countries where inland waters are regarded as a source of fish for human nutrition. However, stocking reservoirs on a large scale also requires vast areas for nurseries. Lack of these with consequent limitation of stocking material has already proved to be a big hindrance in the development of reservoir fisheries in many countries, especially in South Asia. Furthermore, vacant ecological niches exist in reservoirs which need to be filled by suitable species. Experiences in the USSR and to a limited extent in India indicate that silver carp may have a useful role to play in effectively utilizing the phytoplankton otherwise unused. Experiences in Africa, South Asia and the Far East indicate that medium and small reservoirs may respond very effectively to stocking and provide a fish yield many times that of the larger impoundments.

Hybrid fish have great potentials for stocking in both lakes and reservoirs to increase their production. In the USSR, *Coregonus muksun* × *Stenodus leucichthys* and *C. nasus* × *S. leucichthys* are considered suitable for stocking lakes and reservoirs (Bardach, Ryther and McLarney, 1972). The fertile hybrids of sterlet (*Acipenser ruthenus*) × beluga (*Huso huso*) are recommended for large-scale stocking in reservoirs where migrating sturgeons no longer reproduce naturally (Verigin and Nikolsky, 1968). The hybrid, *Catla catla* × *Labeo rohita*, holds great promise for stocking in tropical impoundments (Natarajan, Desai and Mishra, 1976). *Tilapia* hybrids which yield 100% males also have a place in stocking lakes and reservoirs. Many other hybrids need to be tested in lakes and reservoirs. Mass transplantations and introduction of hybrids into inland waters may bring, in their wake, a 'genetic pollution' of indigenous species (*ie*, they may lose their genetic purity). However, reservoirs, marked by restricted spawning habitat for many fishes, especially carps, have already set in motion the production of natural hybrids. Some of these natural hybrids, which exhibit a wide-ranging food spectrum (*eg*, catla × rohu hybrids), need to be artificially propagated on a massive scale to increase fish production in reservoirs.

3.4 *Lagoons*

The lagoons of the Mediterranean region, especially those on the Adriatic Sea are intensively stocked with brackishwater species. Many tropical and sub-tropical countries could benefit by similar measures to derive richer fish harvests from lagoons and backwaters.

4 Conclusions

In summary, it appears evident that the transplantation of a number of anadromous and a large number of non-migratory fish species has resulted in the establishment of many naturally reproducing stocks. Such transplants, said to be 'successful' from the standpoint of establishment of the exotic species, may also be considered successful if they benefit the country or area as a whole. Thus, in New Zealand, the introduction of trout has certainly been considered successful from the angler's viewpoint, albeit partially at the expense of the galaxid fauna upon which they have preyed. On the other hand, the introductions of carp in North America and that of the pumpkinseed (*Lepomis gibbosus*) in Europe are generally considered to have been unfortunate.

Stocking of fry or fingerlings in natural waters (streams and lakes) or in large impoundments, is a practice which varies considerably throughout the world. Thus, in India, many lakes and reservoirs are stocked regularly to produce food fish, and in the USSR a rather massive stocking procedure of eggs and fingerlings is carried on annually especially in lakes and reservoirs but also in rivers. On the other hand, in the USA and Canada, there is very little continuous stocking of either warmwater or coldwater fry or fingerlings except in relatively small salmonid lakes. Experiments with marked fish, followed by check-ups on actual catch, have shown that survival to harvest of fry or fingerling salmonids in streams is extremely low. In fact, on the basis of a ten year study in Canada, all sockeye salmon (*Oncorhynchus nerka*) hatcheries in British Columbia were closed in 1936 because the cost involved in their propagation more than overbalanced the slight benefits derived. (Salmon stocking has now been revived there—see below—but on quite a different basis.) Similarly, the very low returns from stocking of fry or fingerling trout in streams in the USA has meant a drastic change there. These very small trout are now usually stocked only in relatively small lakes; the return in these more stable environments is commensurate with the effort involved.

The stocking of anadromous salmonids (whether for food or for sport fisheries) is another matter in the USA, Canada, Sweden and other countries concerned. Good results from stocking are being obtained by: (*i*) use of artificial spawning channels or boxes where eyed eggs are held to develop, semi-naturally into fry; or (*ii*) by stocking fish of fairly advanced stage (smolts or yearlings) at the proper physiological time and place for migration. The results obtained from such stocking far exceed those of

former years. However, it is not simply a matter of rearing fish semi-naturally or to larger size; many other factors must be considered. For example, the spawning channels require careful design and care, and the success of planted smolts depends largely upon the state of their nutrition, freedom from disease, and genetic constitution.

Stocking, both initially to establish a population and, in many circumstances, continously to maintain it, has been and can be a most useful tool in management of natural waters and large reservoirs. However, these waters—already holding populations of fish which may be predaceous and are likely to be competitive—are quite different from well managed fish ponds which are quite free of any fish when stocked with fingerlings which are then protected and carefully nurtured until they attain marketable size.

Some further appraisal should, therefore, be made of the rather blind stocking (*ie*, where the yield cannot be accredited directly to the fish that are stocked) practised in some areas of the world. Following such appraisal, decisions can then be made as to the advisability of modifying these stocking practices so as to obtain the greatest yield.

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Advances and Problems in Culture-Based Fisheries in Japan

N. Hanamura

Abstract

Culture-based marine fisheries may be defined as 'production systems in which man undertakes commercial fishery production through a series of processes of raising, nursing and catching marine products in the sea, using natural or artificial biotic productivity'.

Culture-based fisheries have been established for decades in Japan with many commercially important marine organisms. These activities have generally involved the capture or culture of seed, artificial propagation of seed to the juvenile stage before being released to the natural environment, and their subsequent capture as adults in fisheries. Species which have been farmed in this way with varying degrees of success in Japan include Pacific salmon (*Oncorhynchus*), ayu (*Plecoglossus*), pil chard (*Sardinops*), herring (*Clupea*), cod (*Gadus*), flounder, kuruma shrimp (*Penaeus japonicus*), clams, scallops (*Pecten*), blue crabs (*Portunus trituberculatus*), red seabream (*Sparus major*), and abalone (*Haliotis*).

The advantages of culture-based fisheries are that firstly, there is a much higher rate of recruitment of harvestable fish from spawners (compared with production in the natural environment), and secondly, they enable expanded exploitation of the basic productivity of the sea

There is still considerable potential for expanding culture based fisheries in Japan. The major constraints to expansion of production of appropriate species are considered.

One of the basic problems facing development of culture-based fisheries in general is that of jurisdiction or latent ownership of culture-based fishery resources. It is inevitable that culture-based fishery production will be exploited in capture fisheries, and there is a need for existing regulations governing fisheries to be examined from a new viewpoint.

Progrès et problèmes des pêcheries basées sur l'élevage au Japon

Résumé

Les pêcheries maritimes basees sur l'elevage peuvent se définir comme des 'systemes de production dans lequel l'homme s'efforce d'obtenir des produits halieutiques à l'echelle commerciale grâce à une série d'operations reproduction, elevage et capture de produits marins en mer, reposant sur la productivité biologique naturelle ou artificielle'

Bien que l'emploi de ce terme soit récent, ce genre d'activite est pratiquée au Japon depuis des decennies, avec nombre d'organismes marins d'importance commerciale Cette activite englobe en general la capture ou l'elevage d'alevins, la propagation artificielle des alevins jusqu'au stade juvénile avant leur libération dans le milieu ambiant natural et la capture ulterieure des adultes. On a cleve au Japon, avec plus ou moins de succès, le saumon du Pacifique (*Oncorhynchus*), l'ayu (*Plecoglossus*), la sardine (*Sardinops*), le hareng (*Clupea*), la morue (*Gadus*), le flet, la crevette Kuruma (*Penaeus japonicus*), les clams, la coquille Saint-Jacques (*Pecten*), le crabe bleu (*Portunus trituberculatus*), la daurade (*Sparus major*) et l'ormeau (*Haliotis*)

Voici les avantages de ce type d'activité: il est possible de recruter bien plus de poissons exploitables au moyen de la reproduction artificielle que par la production en milieu naturel; il est possible d'etendre l'exploitation de la productivité de base de la mer.

Les pêcheries basées sur l'elevage peuvent encore être fortement developpées au Japon et le document examine les principaux obstacles a l'accroissement de la production d'espèces appropriées.

L'un des problèmes fondamentaux auxquels se heurte le developpement de ce genre d'activité en general est celui de la juridiction ou de la propriète latente des ressources maricoles. La production maricole sera inévitablement exploitee dans les pêcheries de capture et la réglementation actuellement en vigueur dans le domaine des pêches devra être réexaminee dans cette optique.

Progresos y problemas de las pesquerías Japonesas basadas en el cultivo

Extracto

El término 'pesquerías marinas basadas en el cultivo' puede definirse como 'un sistema de produccion en el que el hombre se dedica a la producción comercial de peces mediante una serie de procesos de cria, cuidado y captura de productos marinos en el mar, aprovechando la productividad biótica natural o artificial'.

Las actividades de las pesquerías basadas en el cultivo se practican ya en el Japón desde hace décadas con muchos organismos marinos importantes desde el punto de vista comercial. En general, este tipo de actividades comprende la captura o cultivo de semilla, la propagación artificial de la semilla hasta la fase juvenil, antes de su suelta en el ambiente natural, y su posterior captura, como adultos, en la pesqueria. Entre las especies que se han cultivado de esta forma en el Japon, con resultados muy diversos, figuran: salmón del Pacífico (*Oncorhynchus*), ayu (*Plecoglossus*), sardina (*Sardinops*), arenque (*Clupea*), bacalao (*Gadus*), platija, camarón Kuruma (*Penaeus japonicus*), almeja, vieira (*Pecten*), cangrejo azul (*Portunus trituberculatus*), besugo (*Sparus major*) y abalone (*Haliotis*).

Las ventajas de las 'pesquerías basadas en el cultivo' son primeramente, que hay un indice mucho más elevado de reclutamiento de peces explotables provenientes de los parentales (comparado con la producción en el medio ambiente natural) y un mejor aprovechamiento de la productividad basica del mar

Existen aún enormes posibilidades para ampliar este tipo de pesquerías en el Japón. En el presente trabajo se examinan los principales impedimentos que se oponen a la expansión de la producción de especies adecuadas.

Uno de los problemas fundamentales que se plantean para el desarrollo de esas pesquerías en general es la jurisdicción o propiedad latente de los recursos basados en el cultivo. Es inevitable que esos recursos sean explotados en las pesquerías ordinarias de captura, por lo que es necesario examinar desde un nuevo punto de vista las disposiciones que actualmente regulan la pesca.

1 Introduction

Unlike either capture fisheries or aquaculture, culture based fisheries have a relatively short history in Japan, and the actual production generated by this technique has as yet been very small. However, considering the world's increasing demand for marine products, culture-based fisheries seem to have the potential to play an important role in future fisheries production.

Culture-based fisheries, which differ from capture fisheries and aquaculture, can be tentatively defined as: 'Production systems in which man conducts commercial fishery production through a series of processes of raising, nursing and catching marine products in the hydrosphere, using natural or artificial biotic productivity;' or 'production systems that consist of a series of combined processes, such as production of artificially incubated seed and fry, gathering of natural seed and fry, intermediate nursing and release of fry, protection and preservation of released fish in specific farmed areas, management of the environmental conditions of the farmed areas and regulation of fishery and farmed resources'.

2 Artificial propagation of selected marine organisms and related fisheries

The release of seed or fry on natural fishing grounds and their eventual harvest as adult fish has been carried out in Japan for many years. However, this discussion will be limited to some of the striking features of what has been tried in Japan with respect to this process within the past 30–50 years.

2.1 *Salmon in north Japan*

Artificial incubation and release of chum salmon (*Oncor-*

hynchus keta) have been attempted in Japan since the latter half of the nineteenth century, and the scale of release has become more extensive in recent years. The number of chum salmon fry released and the number of adults caught in Hokkaido comprise 60–70% of those in north Japan. The annual numbers of released fry over the past 40 years are shown in Table I.

Recent studies show that the number of adults caught has averaged 1% of the number of fry released since 1965, and recently has increased to 2%. Other species of *Oncorhynchus* have also been artificially incubated and released every year, but they are not nearly as abundant as are chum salmon.

2.2 *Ayu*

The total number of artificially propagated fry of ayu or sweet fish (*Plecoglossus altivelis*) reached 2 000–5 000 million annually between 1940 and 1945. The annual catch during this period was 3 000–8 000 tons. From 1955 to the present, 500–1 500 million ayu eggs have been transplanted every year. The number of artificially propagated fry released during this period was 70–300 million and the annual catch of adults was 4 000–11 000 tons.

The exact annual catch of ayu is hard to estimate,

TABLE I
ANNUAL FRY LIBERATIONS, ADULT RETURN RATE AND EXPLOITATION OF HOKKAIDO CHUM SALMON STOCK FROM 1931–69

Year of liberation	*Liberation in numbers (1 000) of artificially incubated fry*	*Estimated number of return (1 000)*	*Estimated catch of returning adults (1 000)*	*Percentage age of liberated fry returning as adults*
1931	177 170	2 254	1 867	1·27
1932	95 456	1 699	1 516	1·78
1933	145 139	2 140	1 799	1·47
1934	235 869	2 294	1 971	0·97
1935	191 082	2 459	2 034	1·29
1936	187 238	2 665	2 339	1 42
1937	209 088	2 039	1 764	0 98
1938	220 182	1 956	1 578	0 89
1939	276 985	1 684	1 254	0·61
1940	208 415	1 627	1 223	0·78
1941	221 782	2 438	1 805	1 10
1942	206 122	1 657	1 244	0·80
1943	215 252	2 238	1 877	1·04
1944	135 531	2 809	2 401	2·07
1945	165 071	3 212	2 730	1 95
1946	142 126	4 396	3 907	3·09
1947	136 905	2 923	2 609	2 14
1948	156 621	2 063	1 751	1 32
1949	181 626	2 209	1 997	1 22
1950	222 451	3 380	2 994	1·52
1951	189 157	2 413	2 119	1·28
1952	159 517	1 884	1 702	1·18
1953	170 606	2 618	2 170	1·53
1954	269 338	2 960	2 471	1 10
1955	247 922	1 780	1 427	0·72
1956	140 454	1 730	1 425	1·23
1957	361 608	2 941	2 514	0·81
1958	417 238	2 760	2 389	0·66
1959	313 549	3 767	3 407	1·20
1960	203 413	3 812	3 220	1·87
1961	359 489	4 749	3 943	1·32
1962	280 743	3 804	3 408	1·35
1963	272 106	4 501	3 909	1·65
1964	334 463	2 138	1 903	0·64
1965	549 278	4 173	3 595	0·76
1966	272 036	5 287	4 661	1·94
1967	434 729	7 652	6 807	1·76
1968	207 438	6 957	6 343	3·35
1969	361 571	8 321	7 724	2·30
1970	442 101			

because, in addition to the commercial fisheries catch, estimates must be made for the recreational fishing catch, which is thought to be a considerable one.

The average ratio of the number of fish caught to number of fry released is also hard to estimate, because it varies according to the year, the particular water fished, or the fishing district, even within the same river system. Nevertheless, artificial incubation and liberation of ayu is still continued every year, because from experience it is considered that satisfactory results are being achieved.

2.3 *Shellfish*

The annual catch of certain shellfish during the past 30 years has been approximately as follows:

Short-necked clams (*Venerupis*): 60 000–200 000 tons. During the past ten years the catch has remained at a consistent level of 100 000–150 000 tons.

Hard clams (*Meretrix*): 6 000–25 000 tons. During the past ten years, the catch has been much lower (less than 15 000 tons), and generally 5 000–6 000 tons.

Hen clams (*Mactra*): 2 000–13 000 tons. Over the past ten years the catch has been 2 000–5 000 tons—a slight decrease compared with previous years.

Common scallops (*Pecten*): 10 000–20 000 tons during the period 1940–60, with one exceptional catch of 60 000 tons in 1942. From 1960 onward, the catch has decreased to 4 000–10 000 tons. Since 1970, aquaculture of common scallops has increased the catch so remarkably that in 4–5 years the catch has reached an annual 40 000 tons.

For the past several decades, seed of the following shellfish were released in large numbers: short-necked clams—5 000–20 000 million; hard clams—1 000 7 000 million; hen clams—5–500 million; common scallops—100–500 million.

The relationship between the number of seed released and yield is, however, not clear for any of these shellfish. Various factors such as the size of the shellfish when released, environmental conditions in the farming areas, the abundance of natural shellfish resources, and fishing conditions may cause fluctuations in the survival rate, growth and the yield of the released group. This is a major reason why it is difficult to estimate the correlation between numbers of released seed and the yield.

2.4 *Pilchards in southwest Japan*

During the period of 1930–40, there was an annual catch of 1–1·5 million tons of pilchards or sardines (*Sardinops*) in Japan's inshore fishery. This was the highest catch for any species of fish in Japan.

Later the pilchard resources suddenly declined until the annual catch decreased to less than 200 000 tons between 1945 and 1950. This promoted the practice of artificial incubation and liberation of pilchards in the coastal areas of southwest Japan, the most important spawning areas for pilchard populations. Between 1943 and 1945, about 500–2 000 million artificially propagated fry were released annually. However, even on this vast scale of artificial incubation and liberation of pilchards, it was impossible to restore and improve the population.

2.5 *Herring in north Japan*

During the 1920–1935 period, the annual catch of

herring (*Clupea*) was 250 000–500 000 tons. In Japan's fisheries production, herring had been the most important species after sardines. But in 1947–50, the catch and quantity of littoral migrating herring suddenly decreased. So, from 1952 to 1957, a large number of herring seed and fry were released every year.

The method of liberation commonly used at that time was to return herring eggs, which had been washed ashore adhering to seaweeds, to the sea. The number of fry liberated in this way was estimated to be between 500 000 million and 1 000 000 million every year. But, as was the case with sardines, it was impossible to restore and improve the herring fishery resources even on this vast scale of liberation.

2.6 *Cod and flounders in north Japan*

In 1945–50, the populations of cod (*Gadus*) and flounders, which had been important resources in inshore fisheries in north Japan, declined markedly. This promoted artificial incubation and liberation of cod and flounder at a level of several millions or tens of millions but, as was the case with sardines and herring, this liberation of fry did not contribute to the improvement of resources.

3 Recent advances in culture-based fisheries

3.1 *Seto Inland Sea*

Since 1965, Japan's offshore and far-sea fisheries have remarkably increased the country's total fishery production. This expansion of production was chiefly due to the exploitation of new fishing grounds and new resources. The catch in the offshore fisheries in 1965 was 2·8 million tons, while by 1973 it had increased to 4·0 million tons. Similarly, the catch in the far-sea fisheries in 1965 was 1·8 million tons, while in 1973 it increased to 4 million tons. In inshore fisheries, however, the catch over the last 20 years has remained at the same level of about 2 million tons, with a slight decrease in the last three years.

It was in 1962—when the national fishery production was declining—that a project establishing culture-based fisheries was started in the Seto Inland Sea.

In the Seto Inland Sea, the levels of natural resources and catches of high-priced species such as red seabream (*Sparus major*), kuruma shrimp (*Penaeus japonicus*) and blue crab (*Portunus trituberculatus*) have decreased, and the catch is now one half of what it was in previous years.

During 1962–67, for the purpose of improving and increasing those resources, five fish farming centres were established in and around the Seto Inland Sea. In 1967–72, each centre was equipped with facilities for seed production and intermediate nurseries; and in recent years, the Seto Inland Sea Fish Farming Center, National Regional Fisheries Research Laboratory and Prefectural Fisheries Scientific Research Institutions have been co-operating to develop techniques for seed production, intermediate rearing and liberation.

One of the results of this co-operation is that it has been possible recently to produce 200–250 million kuruma shrimp fry (size 1 cm) at a relatively low production cost. Most of the fry are released in the farming areas and in four or five months the released shrimps, which have grown to 11–12 cm or commercial size, appear in the fishery. The proportion of fry released contributing to yield is 0·1–5%, and on some fishing grounds is as high as 10%, though the differences in methods of liberation, environmental conditions during rearing, and fishing conditions may affect these figures.

Recently, 3·0 million red seabream fry (2–3 cm) have been reared annually, but the techniques of their large-scale production have not been established, nor is the production cost low. Therefore it is only possible to release fry on a small scale. It also takes more than two years before these seabream reach harvestable size; consequently not enough information has been obtained to estimate the ratio of the number of fish caught to that of fry released. At the present stage, production of red seabream fry is on such a small scale that most of the seed is used for aquaculture.

3.2 *North Japan*

As was the case with the Seto Inland Sea when the inshore fisheries were declining, aquaculture production of common scallops (*Pecten*) has greatly increased and research into development of techniques in culture-based fisheries of common scallops has been carried out through co-operation between the National Regional Fisheries Research Laboratories and Prefectural Fisheries Scientific Research Institutions. Projects have been undertaken to: develop techniques for collecting their natural seed, prevent natural mortality of juveniles by extermination of predators such as starfish and sea urchins, and increase the survival of juveniles.

Judging from the recent trend of the increases in number of common scallops (excluding the increase from aquaculture production) it may be concluded that this shellfish farming is producing satisfactory results, though the ratio of the number caught to the number of transplanted juveniles has not yet been determined.

Techniques have also been developed to fatten naturally occurring abalones (*Haliotis*) and sea urchins (echinoids) by artificially planting and developing beds of seaweeds which they can use as feed, and to promote effective shellfish farming.

3.3 *Japan Sea and west Japan*

As was the case with the Seto Inland Sea, while the inshore fisheries were declining, research and experiments began in 1972 to increase the farming resources of high priced marine organisms such as red seabream, kuruma shrimp, blue crabs and abalones.

Eight fish farming centres are now being constructed in these areas, under a two–three year plan.

4 The basic theory of culture-based fisheries

The history of the progress in the world sea fisheries during the past hundred years has been a history of the development of the systems of gathering natural marine products. The systems and principles of production have also been formed on this basis.

In time, man experienced 'primary' over-fishing as a result of the increasing catch of natural fishery resources. It was found that continuous catches above the average annual recruitment or influx of a certain

natural resource would lower the age composition and size composition of the catch and, decrease the average catch per unit of fishing effort. It was also found that consecutive heavy catches of spawning fish would bring about a decrease in the quantity of eggs and fry and annual recruitment of fishery resources, and a reduction of reproduction, which would result in 'secondary' overfishing.

It was through these experiences that the theory of maximum sustainable yield from fishery resources developed—a theory which has been used as a basis for co-operative conservation of international fishery resources and the management of fisheries. On the other hand, it was observed that the size of annual recruitment of natural fishery resources was greatly influenced by many factors and could vary by multiples of ten or more. Based on these observations, a theory on the maximum catch per annual recruitment has developed.

However, both of the above theories are concerned with the method of effective fishing. One theory considers how many spawners should be kept and the other theory concerns adjustment of population size to obtain the maximum catch per annual recruitment. These two ideas, lack, however, a practical theory of how to increase catches by artificially and positively expanding biotic production (in number and quantity) during every stage of development and growth of eggs, fry and juveniles.

The author believes that culture-based fisheries have two specific advantages which capture fisheries and aquaculture do not possess.

4.1 *The first advantage*

It is possible to increase the maximum sustainable yield of fishery resources by artificially expanding biotic production of recruits, as shown in Fig. 1. Reproduction curve A shows the relation between the abundance of the spawning population in natural fishery resources and the recruitment accordingly; reproduction curve B shows the same relation as it occurs in culture-based fisheries.

In culture-based fisheries, the mortality of eggs, fry and juveniles at each stage of development can be artificially checked, and the average number of recruits per unit spawner can be several times as large as that in natural fishery resources (Fig. 2).

With respect to fish and shellfish which have been exploited by man, the number of eggs per spawner ranges from a few to several thousand at the minimum, to a maximum of several hundred thousand to several million. The numbers of eggs per spawner per spawning season for selected fish groups can be summarized as follows:

Surf fish and sharks: up to tens of eggs.

Salmon: 2 000–5 000 eggs.

Pilchards (sardines) and herring: between tens of thousands and hundreds of thousands of eggs.

Shrimps and crabs: between several hundred thousand and a million eggs.

Flounders and cod: between several hundred thousand and several million eggs.

It is generally reported that, even for those species spawning millions of eggs in one season, only as many

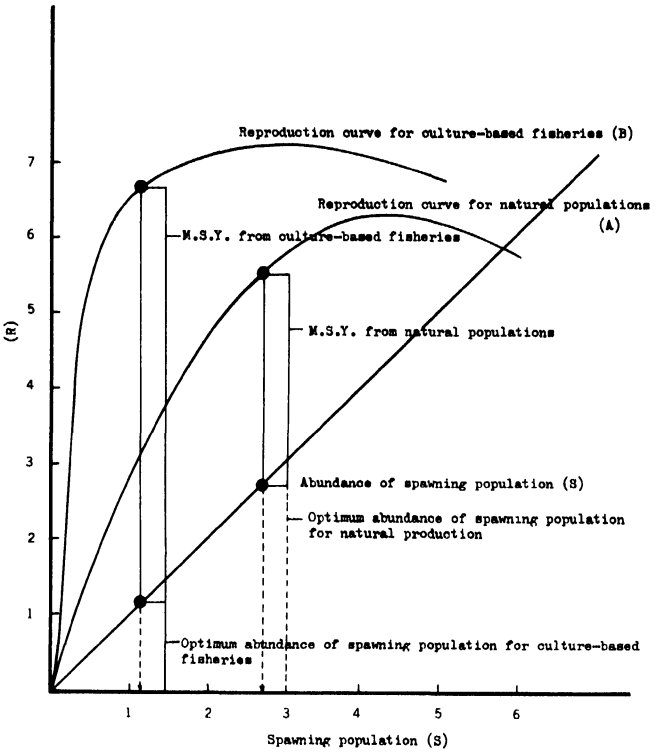


Fig 1. Diagram showing theoretical relationship between abundance of spawning populations and recruitment in natural populations (A) and culture-based fisheries (B) (MSY— Maximum sustainable yield)

eggs develop and survive as the original number of spawners, or a small multiple of this number. The rest either die or are eaten by other organisms during one of the following processes:

(*i*) *Fertilization.* In natural spawning, the fertilization rate varies according to the species of fish. Some have a fertilization rate of over 80–90%, others have a rate of less than 30–50%. This means that at this stage, even with a high fertilization rate, 10–20% of the eggs are lost.

(*ii*) *Incubation.* Fertilized eggs are incubated for time periods that are specific to each species. The process may take place in a spawning nest or a spawning bed, when adhered to the surface of seaweeds or rocks, on the sea bottom, in cracks in a rock, in the bottom sand or while drifting in the water.

Eggs are non-motile and defenceless against predators or unsuitable physical or chemical conditions. Many cases are reported where a sudden change or worsening of environmental conditions necessary for incubation resulted in high mortalities, and eggs are often eaten by other organisms.

There is, however, no detailed quantitative field research data which give accurate estimates of the natural mortality at this stage. It is still hard to estimate the quantitative distribution and mortality of eggs in the field, but many reports suggest that the decrease at this stage is significant.

(*iii*) *Development of fry.* Fry undergo significant decreases in numbers at and after the hatching stage until they grow old enough to be able to feed

themselves. Excepting fry which have a yolk sac as their initial nutritional supply, fry must begin to feed within several hours or days after hatching. At this stage they are so weak, however, that they cannot move around actively in search of food; so those fry which live in areas where food is abundant survive relatively well, while those distributed where food is scarce may often die immediately. Fry also have few defences against predators and population decrease caused by predation is considerable at this stage.

Most fry go through several morphological transformations and move to different environments as they develop and grow. It is reported that they often undergo a significant decrease in numbers as they grow from one stage to another.

(*iv*) *Development of juveniles.* Many reports say that the natural decrease at the juvenile stage of fish is small compared with those at the egg or fry stages. Generally, those fish which are in the upper links of the food chain suffer less from predation, and the natural decrease is comparatively small. Some reports have shown that annual natural mortality is less than 0·1–0·3%, while those organisms in the lower levels of the food chain are more often eaten as food and annual natural mortality is over 0·5–0·6%.

Considering this information, it is suggested that it is possible to produce as many culture-based fishery resources as we need if we can develop methods and techniques to artificially reduce natural population decreases during the early stages of life history.

For example, in Canada, the United States and the USSR, the maximum sustainable yield of Pacific salmon resources is maintained by allowing 30–50% of the spawning migration to escape into rivers to spawn, with the catch being regulated to 50–70% of the returning adults. In Japan, more than 90% of the chum salmon migration return in Hokkaido is caught, and the fishery is maintained by artificial incubation and liberation. Since the artificial incubation and liberation has increased the average number of recruits per unit spawner to more than three times that in natural spawning, only a return of 10% of chum salmon spawners is needed to maintain the resources.

Since 1969, chum salmon fry have been released after intermediate rearing in order to decrease the natural mortality of released juveniles, and it is estimated that the average number of recruits per unit spawner is now over six times as large as that which occurs in natural spawning. The catch of Hokkaido chum salmon, which has been 1·5–3 million fish for 40 years, has increased to an average of 7–8 million fish within the last three years. This is a typical case where a culture-based fishery production system has resulted in a maximum sustainable yield 4–5 times as high as that which is possible in nature.

4.2 *The second advantage*

The second advantage of a culture-based marine fishery is that it enables the exploitation of the basic productivity of the sea so that biotic production of needed fishery resources may be quantitatively increased.

In the biotic community in the hydrosphere there is a balanced food chain comprising phytoplankton, zooplankton and micro-nekton. This is only a small part of the vast circulation of substances in the total ecosystem in the hydrosphere that man is exploiting by reducing marine populations. The remainder of the vast abundance of organisms is untouched by man and it is possible to increase fishery resources by placing a useful biomass into the unutilized part of this ecosystem.

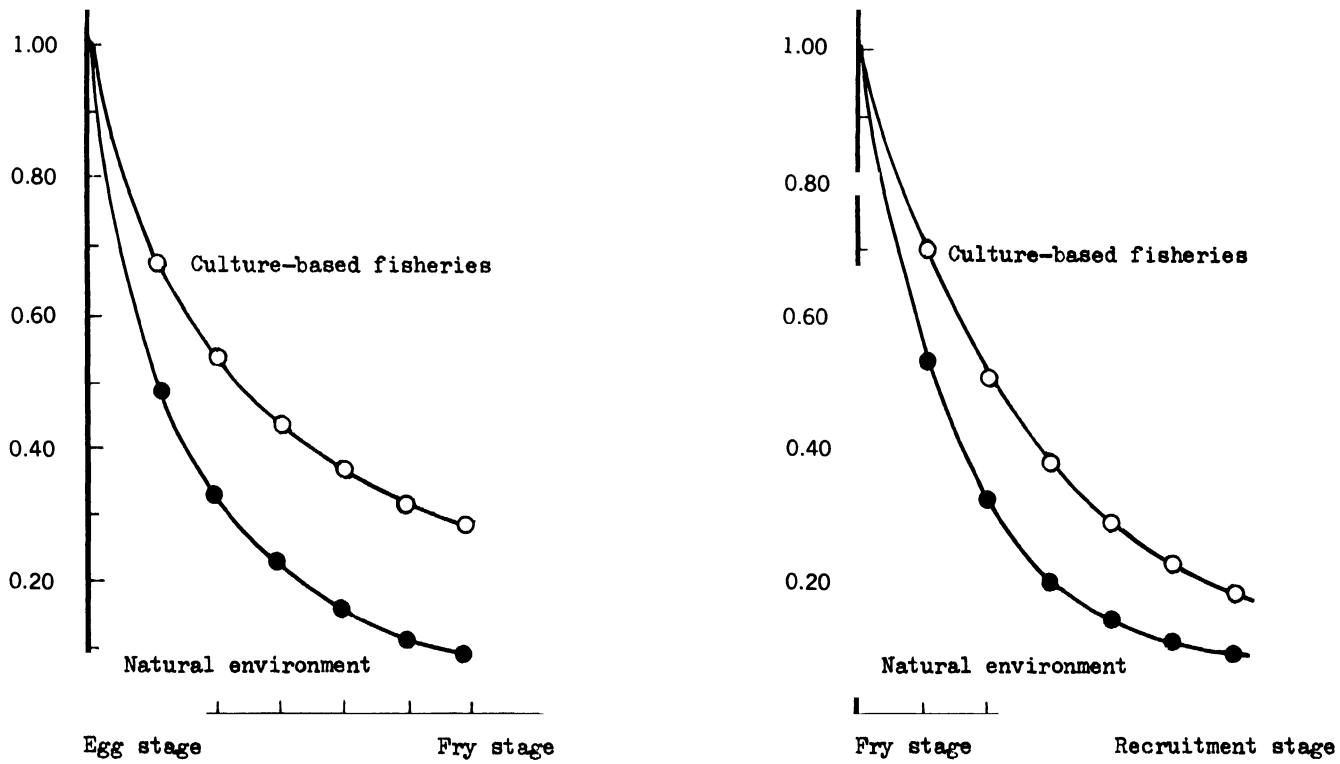


Fig 2. Theoretical survival curve of eggs and juveniles in nature and in culture-based fisheries

On land, man learned in his early history to produce crops by cultivating the soil, burning weeds and bushes to ashes, manuring, sowing, weeding and nursing; on the other hand, man's activities toward fishery production in the hydrosphere have depended largely upon gathering natural products. He has little knowledge and experience to develop fishery production by converting nature. It is possible, however, to foresee and suggest this possibility on the basis of his existing knowledge of fishery biology.

4.2.1 *Fluctuation in abundance of fishery resources and the possibility of resource farming.* Research on the state of herring, pilchard (sardine), mackerel, salmon, flatfish and cod stocks has been conducted for a long time in Japan, Europe and America. The research shows that yearly fluctuations of these fishery resources have varied significantly, as have the numbers of individuals in each year-class of a population. This fluctuation in population size also affects the populations of food organisms accordingly.

Considering the example given in section 4.1 of significantly increased chum salmon populations in Hokkaido compared with historical population levels, there were 2–3 times the number of salmon accommodated in their habitat than was the case under natural conditions. It is not clear which other fish were affected by this excessively large population, but through this process it was possible to utilize more of the basic productivity of the sea by artificially replacing some part of the ecosystem with chum salmon.

4.2.2 *The possibility of artificially increasing the basic productivity in the ecosystem* The ecosystem has a certain fundamental biological productivity governed by physical, chemical or biological characteristics. Biologically, some sea waters are fertile while others are comparatively sterile.

Attempts have been made to convert the fundamental biological productivity in an eco-system by artificially converting its physical, chemical and biological structure, while other attempts have been made to increase biological productivity by changing current systems which affects nutrient supply and water change. Other attempts have been made to increase commercial fishery production by adding nutrients artificially to the sea water and sea bottom so as to promote the growth of phytoplankton and thus increase the biomass that relies on phytoplankton for food.

4.2.3 *The possibility of increasing useful marine life by exterminating predators.* There are many reports on methods and techniques to promote the survival of marine products by exterminating predators or by isolating the commercially important marine organisms from predators at an early stage of their development, *eg*, protection of juvenile salmon by exterminating predators, or protecting the released juveniles of common scallops and kuruma shrimp fry.

5 Problems in the future development of culture-based fisheries

5.1 *Salmon in north Japan*

In north Japan 500–800 million chum salmon fry are produced every year at a cost of less than one yen per individual. The fry of chum salmon which are released in the rivers of north Japan go out to the Aleutian water area, the Bay of Alaska or to the Bering Sea, where they live for three or four years, growing and maturing. They then return to the rivers in north Japan. The number of returns as a proportion of fry released is 0·5–3·5%, with an average of 2%.

Fry weighing 0·3–0·5 g at the time of release have grown into fish of 3 or 4 kg in three or four years when they return. If 500 million artificially-propagated fry were allowed to roam freely in the vast area of the North Pacific at a production cost of Yen 500 million, in three or four years there would be an expected yield of 10 million chum salmon (30 000–40 000 tons at a value of over Yen 10 000 million).

During the sixty years between 1900 and 1960, biological research and technical development were devoted to the improvement of artificial incubation techniques. It was then possible to hatch more than 90% of the artificially fertilized eggs.

As it was found later that 70–80% of the fry were lost by the time they reached the sea, and that 40–50% of those juveniles which went out to sea were lost within a few days, efforts were made to develop a technique for preventing the losses observed during their life in rivers (*ie*, before reaching the sea). Since it is now possible to predict that losses during the riverine and early sea stages can be decreased by one-half to one-third, salmon in north Japan can be expected to increase two-fold from present levels.

It is important, however, to decide whether to develop techniques for immediately increasing the number of released fry by two or three times, or to develop techniques for intermediate rearing and predator extermination, as the means to decrease losses of juveniles. In either case, the basis for technical development should be the results of ecological research on the development and survival of fry at an early stage of their life history.

5.2 *Ayu*

Plans have already been made to produce large quantities of ayu eggs and fry for release, but the relation between the number of released fry and the catch is not as clear as in the case of chum salmon, nor is it clear at which stage of the early life history of eggs and fry is the decrease largest. Nor has it been clarified whether the chief cause of decrease is predators or the physical and chemical conditions of the rivers.

In culture-based fisheries for ayu, therefore, it is necessary to determine the factors causing decreases in juvenile populations through ecological and population dynamics studies.

5.3 *Shellfish*

There has been excellent progress in techniques for mass production of seed and juveniles, and for mass collection of seed in nature for relevant shellfish species such as hard clams, hen clams and scallops.

The relation between the number of juvenile shellfish released and the number caught or collected is not clear, but it has been emphasized that the kinds and quantities of predators living in the farming areas have

an effect on the survival of juvenile shellfish released. It is also known that, for normal growth of released juvenile shellfish, environmental conditions such as the bottom water and bottom deposits of the farming areas are important.

It may be concluded, therefore, that in order to develop culture-based fisheries for shellfish, it is necessary to develop a technique for intermediate rearing of large numbers of juvenile shellfish, to exterminate predators in the farming areas and to promote biological studies.

5.4 *Pilchard, herring, cod and flounder*
There is no special technical difficulty in artificial production of seed of these fish. Though artificial incubation and liberation of their fertilized eggs has been tried on a large scale, the practical results are not clear. But it is considered that a large quantity of fry and juveniles are eaten by other fish, considerably decreasing their numbers. The survival of these fry is also considered to depend upon whether they are provided with abundant food during their early stages.

Concerning the decrease in stocks of pilchard and herring, one of the major contributing factors is thought to be the massive catch of fry of pilchard and small herring. Therefore, before attempting further development of culture-based fisheries for these species, the decreases during the early stages of their life history must be examined.

5.5 *Kuruma shrimp and blue crabs*
There are already prospects of producing seed of kuruma shrimp and blue crabs for release in large quantities at relatively low cost. The relation between the number of released fry and the catch has been partially clarified. It has also been determined that, in order to attain more effective production from release of their seed, it is necessary to reduce predation at the stage of release and for a short period thereafter. The pressing need in culture-based fisheries for these resources, therefore, is to develop a technique for predator extermination at these stages.

5.6 *Abalones and sea urchins*
For culture-based fisheries for abalones and sea urchins, it is necessary to develop a technique for constructing feeding fields where many abalones and sea urchins can congregate and grow. The technical development in this field has attained the level of commercial production. In the near future it will become possible not only to fatten natural abalones and sea urchins, but also to liberate seed and juveniles artificially in the feeding field.

5.7 *Red seabream*
The stage of cheap, large-scale artificial production of red seabream fry for liberation has not yet been reached. Fry of 2 or 3 cm are considered suitable for liberation and it is known that their subsequent mortality is not great. Harvesting of young-of-the-year fish (4–12 cm) is the major factor contributing to decrease in populations.

The problems that demand a quick solution in culture-based fisheries for red seabream are the development of a technique for large-scale artificial production of 2–3 cm fry at low cost, and the protection of small fish released in farming areas from incidental harvesting.

6 Postscript
Finally, consideration should be given to the basic problem common to culture-based fisheries in general; *ie*, the problem of the jurisdiction over ownership of culture based fishery resources. Modern fishery production is predominantly dependent upon gathering naturally produced fishery products. Thus it is inevitable that the fishing grounds for natural and culture-based fisheries production will overlap, and that there will be a mixed catch of natural fishery resources and culture-based fishery production. In order that culture-based fisheries can develop and produce more fishery products in the inshore areas, an examination of the existing systems, regulations and facilities in fishery production is urgently required.

Review of Transplantation and Artificial Recruitment of Anadromous Species

W. J. McNeil

Abstract
Review of the literature reveals that more than 2 000 million juvenile anadromous fishes are produced annually by artificial methods and released into marine basins of the world. Three genera dominate artificial recruitment: *Oncorhynchus, Acipenser* and *Salmo*. *Oncorhynchus*, principally *O. keta*, account for more than 90% of the total number of juveniles reared and released for artificial recruitment.

Transplantations of anadromous fishes have frequently produced disappointing results but there have been instances where introduced stocks have acclimatized to new environments. Self-perpetuating anadromous stocks have been more difficult to establish through transplantation with *Salmo* than with *Oncorhynchus*.

Success of artificial recruitment is best ensured by selecting broodstocks which are native to a hatchery stream or lake. Factors controlling success of acclimatization of introduced stocks of anadromous fishes are not well understood, but success of a transplanted stock is best assured through continuance of artificial recruitment to reduce mortality during early life stages in fresh water.

Examen de la transplantation et du recrutement artificiel d'espèces anadromes
Résumé
Il ressort des ouvrages publiés que plus de 2 000 millions de poissons anadromes juvéniles sont produits annuellement dans le monde par des méthodes artificielles et lâchés dans des bassins d'eau de mer. Trois genres dominent le recrutement artificiel: *Oncorhynchus, Acipenser* et *Salmo*. A *Onchorhynchus*, et surtout à *O. keta* sont imputables plus de 90% des juvéniles élevés et lâchés aux fins de recrutement artificiel.

Les transplantations de poissons anadromes ont souvent donnés des résultats décevants, mais il est des cas où des stocks introduits se sont acclimatés à des environnements nouveaux. L'établissement par transplantation de stocks anadromes autoreproducteurs a été plus difficile avec *Salmo* qu'avec *Oncorhynchus*.

L'on assure mieux la réussite du recrutement artificiel en choisissant des stocks de géniteurs qui sont originaires d'un cours d'eau ou d'un lac d'éclosion. On connaît mal les facteurs dont dépend la réussite de l'acclimatation des stocks de poissons anadromes introduits, mais la

meilleure manière d'assurer une bonne transplantation du stock est de poursuivre le recrutement artificiel de manière à réduire la mortalité pendant les stades initiaux de la vie en eau douce.

Examen de el trasplante y reclutamiento artificial de especies anádromas
Extracto
La bibliografía sobre este tema revela que anualmente se producen por métodos artificiales y se sueltan en aguas marinas de diversas zonas del mundo más de 2 000 millones de formas juveniles de peces anadromos. Tres son los géneros que predominan en este reclutamiento artificial: *Oncorhynchus, Acipenser* y *Salmo*. Los peces del género *Oncorhynchus*, principalmente *O. keta*, representan más del 90% del número total de formas juveniles que se crían y sueltan para aumentar artificialmente las poblaciones.

Los trasplantes de peces anádromos han tenido con frecuencia resultados desalentadores, pero ha habido algunos casos en los que las poblaciones introducidas se han aclimatado al nuevo medio. Ha resultado más difícil establecer poblaciones anádromas que se reproduzcan después espontáneamente mediante trasplante de *Salmo* que con *Oncorhynchus*.

La mejor forma de asegurar el exito del reclutamiento artificial es elegir poblaciones de reproductores nativas de un curso de agua o lago que les sirva de zona de incubación. No se conocen bien cuáles son los factores que determinan el èxito de la aclimatacion de las especies introducidas de peces anadromos, pero la mejor manera de lograr que una población trasplantada se afiance es proseguir el reclutamiento artificial para reducir la mortalidad durante las fases iniciales de su vida, en aguas dulces.

1 Introduction

Strong homing during spawning migrations provides a self-herding mechanism which makes anadromous fishes attractive candidates for aquaculture. Artificial recruitment and transplantation are widely practised, especially in the northern hemisphere. Table I lists marine basins where stocking of six genera of artificially propagated anadromous fishes has occurred.

Several cyprinid fishes, including bream (*Abramis brama*), barbel (*Barbus brachycephalus*), shemaya (*Chalcalburnus chalcoides*), roach (*Rutilus rutilus*), and vimba (*Vimba vimba*), occur in southern seas of the USSR. With the possible exception of *B. brachycephalus*, these cyprinids are not normally found in waters with salinity greater than 10 ppt, and they are sometimes described as semi-anadromous. Even though most or all are stocked artificially, semi-anadromous cyprinids are not included in this review. There is also an anadromous form of ayu (*Plecoglossus altivelis*) which is stocked artificially in Japan, but published information on this programme appears to be limited.

Anadromous fishes have been transplanted to many areas of the world during the past 100 years. Some transplantations have been successful, but many attempts have failed. Salmonidae, particularly Pacific salmon (*Oncorhynchus*), have been most popular for transplantation; but sturgeon (Acipenseridae), striped bass (*Morone saxatilis*), and American shad (*Alosa sapidissima*) have also been transplanted.

TABLE I
MARINE BASINS WHERE STOCKING OF ARTIFICIALLY PROPAGATED ANADROMOUS FISHES HAS BEEN PRACTISED

Basin	*Genera*
North Pacific Ocean	*Oncorhynchus, Salmo, Morone, Alosa*
Sea of Okhotsk	*Oncorhynchus*
Sea of Japan	*Oncorhynchus*
Caspian Sea	*Acipenser, Huso, Salmo, Oncorhynchus*
Black Sea	*Acipenser, Huso, Salmo, Morone*
Baltic Sea	*Salmo, Acipenser*
White Sea	*Salmo, Oncorhynchus*
Barents Sea	*Salmo, Oncorhynchus*
North Sea	*Salmo*
North Atlantic Ocean	*Salmo, Oncorhynchus, Morone*
South Pacific Ocean	*Oncorhynchus*

Artificial recruitment of anadromous fishes annually includes millions of juveniles to supplement wild stocks in marine nursery waters. This practice has been termed 'ocean ranching' (McNeil, 1973, 1975). *Oncorhynchus* is the most popular genus for ocean ranching. Other genera which are growing in importance for this purpose include *Acipenser* and *Salmo* (trout; Atlantic salmon).

This report reviews the history of transplantations of anadromous fishes, describes trends in artificial recruitment, and raises certain biological questions which are important to the success of ocean ranching.

2 History of transplantation

Systematic efforts at large-scale transplantations of anadromous fishes appear to have started in the 1870s, when the USA transplanted *Alosa sapidissima, Morone saxatilis, Oncorhynchus tshawytscha* (chinook salmon), *O. kisutch* (coho salmon), *O. nerka* (sockeye salmon) and *O. gorbuscha* (pink salmon) to various localities in the world. Many countries in both the northern and southern hemispheres have since become involved in large-scale transplantations. Although successful transplantations have usually been the exception, increased knowledge about the ecological requirements of transplanted species and improvements in technology for artificial propagation should increase the success of future efforts.

2.1 *Oncorhynchus*

Establishment of an egg-taking station on the McCloud River, a tributory of the Sacramento River, California, in 1872 heralded the beginning of a programme by the USA to establish runs of *Oncorhynchus* at numerous locations in both hemispheres. Over 100 million eggs were distributed to 17 Atlantic states and Hawaii, USA and to 15 other nations by 1930. Almost 100 separate plantings, involving as many as 30·7 million eggs per planting, were tried. Returning adult Pacific salmon were recorded only in Maine, USA (*O. gorbuscha*); Ontario and New Brunswick, Canada (*O. nerka*); southern Chile (*O. kisutch* or *O. nerka*); and New Zealand (*O. tshawytscha*) (Davidson and Hutchinson, 1938). The runs to Maine, eastern Canada and Chile have since disappeared, but New Zealand enjoys self-perpetuating stocks of *O. tshawytscha* (Idyll, 1970).

Since the beginning of the twentieth century, there have been numerous other programmes to transplant *Oncorhynchus*, involving hundreds of millions of eggs and young fish. Ricker's (1972) excellent review and analysis of transplantations of *Oncorhynchus* reveals that results have been highly inconsistent. There have been instances where trans plantations failed to produce evidence of returning adults. In cases where adults did return, it was not uncommon for the runs to decline and eventually disappear.

No adult *O. gorbuscha* returned from 65·5 million eggs transplanted from Alaska to Washington State, USA, over the period 1922–32, and 1·5 million eggs transplanted from Canada over the period 1948–56 produced a low return of 0·07%. Nevertheless, the transplantation of only 0·2 million eggs from one stream to a nearby stream in Washington State produced a 1% return of adults, which represented relatively good marine survival for *O. gorbuscha* (Ellis and Noble, 1959).

Another successful transplantation of *O. gorbuscha* occurred in Alaska in 1964 when 1 800 mature adults were

moved 30 km from a donor stream and released to spawn naturally in Sashin Creek (McNeil *et al*, 1969). Returning runs of adults from this transplant have returned to Sashin Creek in numbers varying between 6 000 and 13 000 annually between 1966 and 1974 (W. R. Heard, personal communication).

In the past 20 years there have been several attempts to transplant *O. gorbuscha* within British Columbia, Canada. Most attempts failed although adults returned to recipient streams for several years in some cases (Walker and Lister, 1971). When transplanted from British Columbia to Newfoundland, Canada, adult *O. gorbuscha* returned in sizeable numbers initially, but the runs soon declined (Lear, 1974). Releases of *O. gorbuscha* in Maine in the early 1900s produced disappointing results (Bigelow and Schroeder, 1953).

Technical problems interfered with the first introductions of *O. gorbuscha* to the Barents and White Seas from the eastern USSR in 1956 and 1957, but in 1960 more than 100 000 adult *O. gorbuscha* returned to northwest USSR streams from a release of 15·3 million juveniles. The runs declined to much lower levels for a period after the large return in 1960, but Kamyshnaya and Smirnov (1968) felt that naturally reproducing populations may have become established. This conclusion is reinforced by more recent returns of several hundred thousand adult *O. gorbuscha* to northwest USSR in 1973 and 1975 (S. I. Doroshev, personal communication). There are recent reports of *O. gorbuscha* from the northwest USSR occurring in Norwegian streams (Y. Harache, personal communication). The Soviets have also experimented with the acclimatization of *O. gorbuscha* to the Black Sea (Shaverdov *et al*, 1962) and the Baltic Sea (Thurow, 1974). Only a few adult *O. gorbuscha* have been caught in the Black Sea, but several hundred were caught in the Baltic Sea in 1975 (S. I. Doroshev, personal communication).

Several transplantations of *O. keta* (chum salmon) have been attempted in the USSR since 1929, when eggs were transplanted from the Amur River to Lake Baikal and the Ob Basin (Azbelev *et al*, 1962). No returning adults were observed. From 1933 to 1939, a total of 9 million *O. keta* were transplanted from eastern to northwestern USSR, but there were no returning adults (Kossov, 1960). However, transplantations of *O. keta* to the Caspian Sea in the sixties produced initial returning runs of up to 1 500 adults (Magomedov, 1970). S. I. Doroshev (personal communication) reports a lack of suitable natural spawning streams entering the Caspian Sea, and resumption of transplantations of *O. keta* must await construction of hatcheries. Doroshev also reports that introduction of *O. keta* to the Baltic Sea in 1970 failed.

Transplantations of *O. kisutch* from the USA to Korea in the late sixties were unsuccessful (Atkinson *et al*, 1973). However, recent transplantations of *O. kisutch* from the Pacific coast to the Great Lakes, USA, have succeeded (Scott and Crossman, 1973). Projects are presently under way to acclimatize *O. kisutch* to New England, USA (Joyner and Mahnken, 1975) and to Chile (FAO, 1969).

Transplantations of anadromous stocks of *O. nerka* have mostly failed (Ricker, 1972). Two exceptions are transplantations to Lake Washington and Frazer Lake, USA. *Oncorhynchus nerka* was introduced into Lake Washington from the nearby Skagit River in 1936 (Royal and Seymour, 1940). Success remained in doubt for many years, until the population exhibited spectacular increases in the sixties and produced an escapement of 200 000 spawners in 1969 (Ames, 1970). Frazer Lake, on Kodiak Island, Alaska, was first stocked with *O. nerka* from nearby lakes in 1951. Returning runs had increased to 24 000 adults by 1970 (Russell, 1972).

Other recent transplantations include unsuccessful attempts to move *O. keta* from the USA to Korea (Atkinson *et al, 1973*) and successful attempts to move *O. tshawytscha* from the Pacific coast to the Great Lakes, USA (Scott and Crossman, 1973). Projects are under way to acclimatize Japanese stocks of *O. keta* (T. Joyner, personal communication) and *O. masou* (masu salmon) (FAO, 1973) to Chile.

2.2 *Salmo*

The modern history of artificial propagation of *Salmo* dates back to 1855 in Europe and 1864 in North America (Idyll, 1975). Numerous transplantations of *Salmo* have been made in the past, resulting in widespread distribution of *S. trutta* (brown trout) and *S. gairdneri* (rainbow trout) in suitable freshwater habitats throughout the world. Nevertheless, attempts to establish self-perpetuating anadromous stocks of *Salmo* through transplantation outside of the natural range of a particular species have usually failed. Some exceptions are small anadromous populations of *S. trutta* which have become established in British Columbia, Canada (Carl *et al*, 1959), Newfoundland, New Brunswick and Nova Scotia, Canada (T. G. Carey, personal communication), and the Falkland Islands (South America) (MacCrimmon and Marshall, 1968). A small population of introduced *S. gairdneri* has also become established on Prince Edward Island, Canada (MacCrimmon, 1971; T. G. Carey, personal communication).

Repeated attempts to transplant anadromous stocks of *S. salar* (Atlantic salmon) outside of their natural range have failed. Efforts were made over approximately a 30 year period to acclimatize *S. salar* to British Columbia, Canada. Some adults returned from the ocean but the species did not become established (Clemens and Wilby, 1961; Carl *et al*, 1959). Attempts to acclimatize *S. salar* to New Zealand produced freshwater populations rather than anadromous, but these have virtually disappeared (Flain, 1972). Experimental transplantations of *S. salar* into barren streams in western Europe are being tried (Arig non, 1973; Thurow, 1974), but success has not been reported.

The USSR initiated a programme in 1965 to acclimatize anadromous stocks of *S. gairdneri* from the west coast of North America to river basins entering the Sea of Azov and the Black Sea (Karpevich, 1967; Bogdanov *et al*, 1967). The first maturing fish were observed in 1970 (Bogdanov and Doroshev, 1971). Small anadromous populations may have become established along the Caucasus coast of the Black Sea, but the Sea of Azov appears to be unsuited for *S. gairdneri* (S. I. Doroshev, personal communication). Doroshev also reports that the introduction of *S. gairdneri* to the Caspian Sea in 1973 produced several hundred returning adults in 1975.

2.3 *Acipenser and Huso*

The great majority of sturgeon are harvested in the USSR, but Iran also has an important fishery. Principal commercial species are *Acipenser stellatus* (stellate sturgeon),

A. güldenstädti (Russian sturgeon) and *Huso huso* (beluga), all of which are native to the Caspian and Black Seas (including the Sea of Azov). Other important commercial species include *A. nudiventris* (ship sturgeon) (Aral, Black and Caspian Seas), *A. ruthenus* (sterlet) (Black and Caspian Seas) and *A. baeri* (Siberian sturgeon).

Transplantation of *A. stellatus* to the Aral Sea (Isayev, 1961) has not been successful according to S. I. Doroshev (personal communication), who also states that a parasite introduced to the Aral Sea with *A. stellatus* from the Caspian Sea almost destroyed the important native sturgeon (*A. nudiventris*). Acclimatization of *A. güldenstädti* to the Baltic Sea and a hybrid sturgeon (*H. huso* × *A. ruthenus*) to the Sea of Azov has been tried (Karpova and Kutyanina, 1969). However, introductions of hybrids have been stopped to avoid creating problems with natural gene pools (S. I. Doroshev, personal communication). Other transplantations being attempted include the introduction of *A. baeri* (Siberian sturgeon) to the Baltic Sea (Karpevich and Lukonina, 1970 and 1971) and the Caspian Sea (Karpevich and Lukonina, 1971 and 1972) and *A. ruthenus* (sterlet) to the Baltic Sea (Karpevich and Lukonina, 1970). Success with *A. ruthenus* seems doubtful, since this is normally not an anadromous species (S. I. Doroshev, personal communication).

2.4 *Morone*

The transplantation of a few hundred juveniles of *Morone saxatilis* from the Atlantic to the Pacific seaboard of the USA in 1879 and 1882 led to the establishment of a fishery within 10 years (Idyll, 1970). San Francisco Bay in central California was the site of the two transplantations (Anon., 1946), and *M. saxatilis* has since spread southward into southern California and northward into Oregon (Scott and Crossman, 1973). Important fisheries exist along the Pacific coast of the USA, where *M. saxatilis* may have become more abundant than in its native range (Anon., 1946).

The Soviets initiated a programme in 1965 to introduce *M. saxatilis* to southern seas of the USSR (Bogdanov *et al*, 1967). Approximately 8 000 juveniles from the USA were released into the Black Sea, Sea of Azov and Caspian Sea from 1965 through 1971, and adults from these transplants were first observed in 1970 (Bogdanov and Doroshev, 1971; P. A. Moiseyev, personal communication). It is probably too early to determine whether this species is acclimatizing successfully in the USSR. There is also a report (FAO, 1972) that *M. saxatilis* has been transplanted from the USA to South Africa for acclimatization, but it is uncertain whether the purpose is to establish a freshwater or an anadromous population.

2.5 *Alosa*

Alosa sapidissima was first transplanted from the Atlantic to the Pacific coast of the USA in 1871, when 10 000 fry were released into the Sacramento River in central California. Subsequent introductions to the Sacramento involved 35 000 fry in 1873 and 564 000 fry from 1876 to 1880 (Bowen, 1970). The first mature adults returned to the Sacramento River in 1877 and a commercial fishery for *A. sapidissima* had become well established by 1914 (Cleaver, 1951).

Other introductions of *A. sapidissima* to the Pacific coast of North America occurred in 1885 and 1886, when about 900 000 fry from the Atlantic coast were planted in the Columbia River (Oregon and Washington). However, adult shad, apparently originating from earlier plantings in the Sacramento River, had already been observed in the Columbia River (Cleaver, 1951). *A. sapidissima* is now established from southern California to Cook Inlet, Alaska, in North America and has spread across the North Pacific Ocean to Kamchatka (Scott and Crossman, 1973).

3 Trends in artificial recruitment

Anadromous species produced throughout the world by artificial methods and released into marine waters presently number more than 2 000 million juvenile fishes annually, and the number is increasing steadily. *Oncorhynchus* accounts for more than 90% of this production, with *Acipenser* and *Salmo* constituting most of the remainder.

3.1 *Oncorhynchus*

Ocean ranching of Pacific salmon has been a continuous activity since the late 1800s, especially in the northwest USA and Japan. *O. tshawytscha* accounts for about 70% of the number of juveniles produced artificially in the northwest USA; the remaining 30% consists mostly of *O. kisutch*, although interest in artificial propagation of *O. keta* is emerging. About 90% of the juveniles released from Japanese hatcheries are *O. keta*, with the remainder consisting primarily of *O. gorbuscha* and *O. masou*.

Early hatchery programmes were discontinued in Canada and Alaska in the thirties. Canada's re-entry into ocean ranching in the sixties made use of spawning channels for *O. nerka*, *O. gorbuscha* and *O. keta*. Construction of hatcheries for *O. kisutch* and *O. tshawytscha* has recently begun, and Canada has embarked upon a 20 year programme to increase substantially the production of *Oncorhynchus* in British Columbia (Anon., 1975). The State of Alaska has also taken initiatives to expand ocean ranching of *Oncorhynchus*, including legislation (passed in 1974) which allows private parties to produce juvenile salmon in hatcheries (McNeil, 1975).

Artificial propagation of *Oncorhynchus* has been practised in the USSR since at least the late twenties, when the Soviets first undertook transplantations of large numbers of fish (Azbelev *et al*, 1962).

Development of a modern hatchery system was initiated in eastern USSR in the fifties and combined annual releases of juvenile *O. keta* and *O. gorbuscha* from hatcheries on Sakhalin Island had surpassed 600 million by the late sixties (Kanid'yev *et al*, 1970) and is presently approaching 800 million (S. I. Doroshev, personal communication). Hatcheries elsewhere in eastern USSR, in northwest USSR and on the Caspian Sea also produce *Oncorhynchus*, but the major effort is centred on Sakhalin Island.

Table II summarizes statistics on approximate numbers of juvenile *Oncorhynchus* produced by artificial methods at various locations in the world. These statistics are probably conservative, since some date back to 1966. They indicate, nevertheless, relative levels of artificial recruitment for the various species and geographical areas where ocean ranching is practised with *Oncorhynchus*.

3.2 *Salmo*

Present levels of artificial recruitment of anadromous stocks of *Salmo* are much lower than for *Oncorhynchus*, even though artificial propagation and transplantation of

Salmo has a longer history than for *Oncorhynchus*. Anadromous stocks of *Salmo* appear to be more difficult to propagate artificially than *Oncorhynchus* even though similar procedures are employed.

The largest programme for artificial recruitment of anadromous *Salmo* is centred in the Pacific northwest of the USA, where mainly *S. gairdneri* are produced along with small numbers of *S. clarki* (cut-throat trout) for the primary benefit of sport fisheries. Sweden has pioneered the development of artificial recruitment for *S. salar* and is a leader in the application of modern hatchery technology. Other areas where artificial recruitment of *S. salar* is important are the Atlantic coasts of the USA and Canada and northwest USSR.

Statistics on approximate numbers of juvenile anadromous *Salmo* produced by artificial methods at various locations in the world are summarized in Table III. Some of these statistics date back several years, so the estimates are probably conservative indicators of current levels of hatchery production. They indicate, nevertheless, relative levels of artificial recruitment for the various species and geographical areas where ocean ranching is practised with *Salmo*.

3.3 *Acipenser and Huso*

Artificial propagation of sturgeon dates back to 1869 (Mil'shteyn, 1969) but technical problems impeded progress with sturgeon culture for many years. Recent advances in technology have allowed increases in artificial recruitment in the USSR and Iran to compensate for losses

TABLE II
APPROXIMATE NUMBERS OF JUVENILE *Oncorhynchus* RELEASED ANNUALLY INTO MARINE BASINS

Country and region	*Millions of juveniles*					
	O. keta	*O. gorbuscha*	*O. tshawytscha*	*O. nerka*	*O. kisutch*	*O. masou*
USA						
Northwest states[a]	9	1	210	1	76	0
Alaska[b]	1	2	1	1	1	0
New England states[c]	0	0	1	0	1	0
Canada						
British Columbia[d]	55	20	1	90	1	0
USSR						
Pacific coast[e]	337	457	0	9	5	0
White and Barents Seas[f]	0	4	0	0	0	0
Caspian Sea[g]	0	0	0	0	0	0
Japan[h]	785	39	1	1	1	20
Republic of Korea[i]	1	0	0	0	2	0
Approximate total	1 188	523	214	102	87	20

[a] Anon. (1974) gives 1973 statistics
[b] These statistics are unpublished and represent approximate levels of production in 1974 from public hatcheries (mostly experimental)
[c] Joyner and Mahnken (1975)
[d] Statistics are approximations for 1973 derived from various progress reports of the International Pacific Salmon Fisheries Commission and Canada Department of Environment which are not cited here
[e] Statistics for 1974 provided by S. I. Doroshev (personal communication)
[f] Thurow (1974) includes statistics on hatchery release of pink fry for 1973 in northwest USSR
[g] Approximately 2 million *O. keta* were released annually in the mid sixties, but artificial recruitment has been suspended until hatcheries can be constructed (S. I. Doroshev, personal communication)
[h] Unpublished statistics from Japan Fishery Agency for 1973
[i] Atkinson *et al* (1973) includes statistics for 1973

TABLE III
APPROXIMATE NUMBERS OF JUVENILE *Salmo* RELEASED ANNUALLY INTO MARINE BASINS

Country and region	*Millions of juveniles*			
	S. gairdneri	*S. salar*	*S. trutta*	*S. clarki*
USA				
Northwest states[a]	26	0	0	*
New England states[a]	1	1	0	0
Canada				
Pacific coast[b]	1	0	0	0
Atlantic coast[c]	0	1	0	0
USSR				
White and Barents Seas[d]	0	2	0	0
Baltic Sea[d]	0	1	0	0
Black Sea[d]	0	0	0	0
Caspian Sea[d]	0	0	0 5	0
Scandinavian countries				
Baltic Sea[e]	0	2	*	0
Atlantic Ocean[f]	0	0·3	*	0
Other European countries				
Baltic Sea[g]	*	*	*	0
Atlantic Ocean[f]	0	0·5	*	0
Approximate total	28	8	1	

[a] Anon. (1974) gives 1973 statistics
[b] Canada Department of Fisheries and Forestry (1971) gives projected hatchery production
[c] Thurow (1974) includes statistics for 1973
[d] Statistics for 1974 provided by S. I. Doroshev and P. A. Moiseev (personal communication)
[e] Idyll (1975) gives *S. salar* smolt production from Sweden as less than 2 million for 1965 but does not include Finland
[f] Statistics for 1973 provided by O. A. Mathisen (personal communication)
[g] Thurow (1974) mentions small releases of *S. gairdneri*
* Some hatchery production, probably considerably less than 1 million annually. Statistics not available.

of wild stocks from hydro-electric power developments and other activities of man (Gordienko, 1970; H. Emadi, personal communication). The Soviets have also been experimenting with artificial spawning channels for sturgeon since 1966 (Khoroshko and Vlasenko, 1970).

Artificial recruitment of juvenile sturgeon is approaching 100 million fish annually in the USSR and 5 million in Iran. Statistics given by Legeza (1971) for artificial propagation of sturgeon in the Caspian Basin provide insight into the rapid expansion of sturgeon farming. From 1955 to 1968, according to Legeza, the number of juveniles raised artificially at Caspian hatcheries increased from less than 3 million to more than 50 million annually. The principal species raised in 1968 were: *A. stellatus* (16 million), *A. güldenstädti* (15 million), *H. huso* (13 million) and *A. nudiventris* (6 million). S. I. Doroshev (personal communication) reports that artificial recruitment of sturgeon juveniles into the Caspian Sea has recently reached 70 million juveniles. He states that releases elsewhere in the USSR include about 15 million *A. stellatus* and *H. huso* into the Sea of Azov and 3 million *A. nudiventris* into the Aral Sea.

An unproductive practice of releasing unfed sturgeon fry was discontinued in Iran in 1965, where a modern sturgeon hatchery is now able to produce annually 5·5 million sturgeon juveniles weighing 3–5 g each. Plans have been made to construct additional sturgeon hatcheries in Iran (H. Emadi, personal communication).

3.4 *Morone*

Limited artificial propagation of *Morone saxatilis* in the USA is primarily for stocking freshwater lakes and reservoirs to provide sport fishing. Juveniles released into marine waters from hatcheries currently number less than 1 million annually (Anon., 1974).

3.5 *Alosa*

Artificial propagation of *Alosa sapidissima* for stocking marine or fresh waters is no longer practised in the USA.

4 Discussion and conclusions

In an article on use of the seas for aquaculture, Joyner (1975) states: 'Salmon, of all marine species, seem to offer the best prospects for early development of an aquaculture system capable of taking advantage of the natural productivity of ocean ranges'.

Joyner's observation is reinforced by past experience and by recent trends in ocean ranching which predominantly involves artificial recruitment of salmonid fishes, particularly *Oncorhynchus*. More than one half of the total number of juvenile salmonids presently recruited artificially to marine waters are *O. keta*.

Japan has a large programme for artificial recruitment of a single species (*O. keta*) which may serve as an indicator of future growth of ocean ranching. A study of artificial recruitment of *O. keta* from Japanese hatcheries was recently reported by Okamoto (1975) who concluded that Japan is very close to realizing an annual average of 10 million hatchery adults returning to coastal fisheries. This level of production is equivalent to about 25% of the combined harvest of all Pacific salmon species caught by Japan, mostly in international waters. There is every indication that Japan will continue to increase artificial recruitment of Pacific salmon and that the USSR, Canada and USA will follow the lead of Japan.

A somewhat parallel expansion in artificial recruitment appears to be taking place with sturgeon in the Caspian Sea. Emadi (personal communication) reports that Iran plans to increase artificial recruitment of sturgeon from about 5 million juveniles annually to 20 million by 1980. The USSR is also expanding its programme of artificial recruitment of sturgeon into the Caspian Sea.

The most consistent successes with artificial recruitment of salmonid fishes have occurred when stocks native to the hatchery stream have been used as brood stock. Transplantations of stocks, on the other hand, have frequently resulted in poor returning runs of maturing fish which were unable to maintain themselves without continued use of artificial recruitment.

Each stock of an anadromous species is adapted to a unique combination of environmental factors in fresh water, even though many stocks may intermingle freely in marine waters. Homing behaviour and genetic control over time of maturation ensures that discrete stocks segregate in space and/or time for reproduction. Homing is highly developed in salmonids (Hartman and Raleigh, 1964; Hasler, 1966; Royce *et al*, 1968). Evidence is mounting that homing in salmonids is partly inherited (Bams, in press; Brannon, 1972; Raleigh, 1971), although final recognition of home waters is in response to environmental cues to which the fish become conditioned early in life (Brett and Groot, 1963; Sutterlin and Gray, 1973; Ueda *et al*, 1967).

Transplantations of anadromous fishes have commonly failed to produce self-sustaining runs where no provisions were made to perpetuate transplanted stocks with artificial recruitment. In a number of such cases, adult fish returned from sea over one or more cycles before the stock disappeared.

It should be expected that losses from natural mortality and straying will increase for any stock that is transplanted. Under the best of circumstances, mortality from egg deposition to the time juveniles emigrate to sea is high under conditions of natural reproduction. Even though salmonid fishes have relatively high survival (and low fecundity) in comparison to other anadromous fishes, egg-to-fry survival is typically less than 10% in suitable spawning habitats. Mortality after fry emergence can reduce total freshwater survival of some stocks of salmonids to less than 1% of potential egg deposition by the time juveniles emigrate to sea. For a transplanted stock where fecundity may average 4 000 eggs per female, marine survival of much less than 5% would likely lead to extinction; and artificial recruitment may be the only alternative, assuming a low level of survival at sea. Even with artificial recruitment, the success of a transplanted stock may still be determined by the ability of the fish to acclimatize to new environmental experiences. Factors determining the success of acclimatization may include: (*a*) time of maturation; (*b*) photoperiod during time juveniles migrate to sea and during maturation; (*c*) temperature and flow regimes of hatchery water source and stream and estuarine waters through which fish must migrate to and from sea; (*d*) time of seaward migration of juveniles; (*e*) oceanic temperature regimes; (*f*) productivity of marine nursery waters; (*g*) competitor and predator species.

There have been substantial improvements in the technology for artificial recruitment of anadromous fishes over

the past 20 years. At least partially resolved are many technical questions on maturation of brood fish, incubation of eggs and larvae, feedlot rearing of juveniles, and nutrition and diseases of fish. Unfortunately, knowledge has lagged in two important areas—genetics and the carrying capacity of natural nursery waters. Of immediate concern is the unknown effect of artificial recruitment on genetic composition of wild stocks. Important technical questions on selection of brood fish, maintenance of genetic diversity in artificially-recruited stocks, selective breeding, *etc*, require long-term research. Questions related to the carrying capacity of nursery waters may eventually lead to the establishment of guidelines on the numbers of juveniles, time and size of releases, *etc*, required for artificial recruitment into various basins to realize maximum production from marine waters for utilization for food and in sport fisheries.

The continued welfare of natural stocks must always remain a high priority, and 'risks' associated with any programme of transplantation and/or artificial recruitment of anadromous fishes must be recognized. Biological risks include transmission of epizootic diseases, competition for food and space, predation, and possible loss of genetic adaptation to the natural environment. There are other risks relating to management of fisheries, since a successful hatchery stock will tolerate a much higher rate of exploitation than a wild stock. Thus, extra precautions must be exercised in regulating fisheries on mixed populations of artificially and naturally recruited fish. A very necessary and potentially productive area for future research will be the assessment of risks as well as benefits resulting from transplantation and artificial recruitment of anadromous fishes.

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Salmon Propagation in Japan

T. Kobayashi

Abstract

Of the six species of Pacific salmon (*Oncorhynchus*) occurring in Japanese waters, chum salmon (*O. keta*) is the most important in commercial fisheries, followed by pink (*O. gorbuscha*) and masu (*O. masou*) salmon. Commercial catches of chum salmon in Hokkaido declined in the late nineteenth century to an average annual level of 3 million fish, but have increased significantly since 1970 (up to 9·6 million in 1974). This recent increase in catches has been attributed to improved techniques in the artificial propagation programme for chum salmon.

The two principal regions with natural salmon populations in Japan are Hokkaido Island and Honshu on the mainland Artificial propagation of salmon has been practised for almost 100 years in Japan, and it is still an important tool in maintaining population levels which are affected by continued changes and degradation of riverine environments. In fact, 70–80% of the salmon fry migrating from rivers to salt water have been reared in hatcheries.

While salmon hatcheries in Japan have been privately owned in the past, all salmon hatcheries in Hokkaido were taken over by the local government in 1934, an action which has led to a well co-ordinated salmon propagation programme in this region. Adult broodstock are collected in river traps and stripped immediately Eggs at most hatcheries are incubated in well water at a constant 8°C water temperature. While the earlier practice was to release fry when the yolk sac was absorbed, recent experiments have shown that feeding of fry for up to 30 days before release results in a significant increase in rate of adult return. This additional period of rearing before fry release is thought to have contributed significantly to the recent increase (since 1970) in chum salmon populations.

Numbers of fry produced annually in Hokkaido hatcheries from 1965 to 1974 average 400 million for chum salmon and between 11 and 140 million for pink salmon. The average rate of adult return from chum salmon fry released increased from 1·08% in the period 1952–55 to 2·20% in 1966–69. The hatchery production costs for fry from 1962 to 1969 were estimated to be Yen 1·65 (US$0·05) each and the cost of producing one returning adult was estimated to be Yen 126·2 (US$0·42) or Yen 36 1 (US$0·12) per kg in the same period. The latter value compared favourably with the landed value of an adult salmon of Yen 600 (US$1·98).

La reproduction des saumons au Japon

Résumé

Des trois espèces des saumons du Pacifique, *Oncorhynchus*, que l'on trouve dans les eaux japonaises, le saumon chien (*O. keta*) est celui que l'on rencontre le plus souvent dans les pêcheries commerciales, suivi par le saumon rose (*O. gorbuscha*) et le saumon japonais (*O. masou*). A Hokkaido, les prises commerciales de saumon rose ont dimunué à la fin du dix-neuvième siècle jusqu'à se stabiliser à une moyenne annuelle de 3 millions de poissons, mais elles ont considérablement augmenté depuis 1970, et ont atteint 9,6 millions en 1974. Cette augmentation récente des prises a été attribuée aux progrès des techniques utilisées dans les programmes de reproduction artificielle du saumon chien.

Les deux régions où l'on trouve les principales populations naturelles de saumons sont, au Japon, celle de l'île d'Hokkaido et, à l'intérieur des terres, la région de Honshu. Il y a près de 100 ans que la reproduction artificielle des saumons est pratiquée au Japon et c'est en grande partie grâce a elle que l'on parvient a en maintenir le niveau de population, en depit des modificationset de la degradation constante de l'environnement riverain. En fait, de 70 à 80 pour cent des alevins de saumons migrant des rivières en mer ont ete eleves en stations d'alevinage.

Autrefois, les stations d'alevinage etaient, au Japon, des entreprises privées, mais à Hokkaido, toutes celles qui se consacrent à la reproduction des saumons ont été prises en main en 1934 par le gouvernement local ce qui a permis de bien coordonner les programmes de reproduction de saumons dans la région Les geniteurs adultes sont reunis dans des pièges en rivière et immédiatement depouilles de leur frai ou de leurs œufs. Dans la plupart des stations d'alevinage les œufs sont mis en incubation dans de l'eau de puits maintenue constamment à la température de 8°C Dans les premiers temps, on avait l'habitude de lâcher les alevins avant que le sac vitellin se soit resorbé, mais des experiences recentes ont montre que l'on obtenait une augmentation considerable du nombre d'adultes de remontée en continuant à alimenter les alevins pendant 30 jours avant de les lâcher. On pense que c'est à cette periode d'élevage supplémentaire avant le lâchage des alevins qu'est due en grande partie la croissance des populations de saumons chiens que l'on a constatée depuis 1970.

La production d'alevins des stations d'alevinage de Hokkaido est annuellement en moyenne de 400 millions pour les saumons chiens et de 11 à 140 millions pour les saumons roses. Le nombre d'adultes de remontée obtenus a augmente en moyenne, pour les saumons chiens, de 1,08% de 1952 à 1955, de 2,20% de 1966 à 1969 Les coûts de production dans les stations d'alevinage, entre 1962 et 1969, etaient estimes à Yen 1,65 (US$0.05) par alevin et à Yen 126,2 (US$0,42) par adulte de remontée, soit Yen 36,1 le kilo (US$0,12) prix que l'on peut considerer comme favorable par rapport à la valeur du saumon adulte mis à terre, qui est de Yen 600 (US$1,98).

Propagación del salmon en el Japón

Extracto

De las tres especies de salmón del Pacifico, *Oncorhynchus*, que se encuentran en aguas japonesas, el salmón chum (*O. keta*) es la más importante en las pesquerías comerciales, seguida por el salmón rosado (*O. gorbuscha*) y el salmón masu (*O. masou*). Las capturas comerciales de salmón chum en Hokkaido disminuyeron a finales del siglo XIX a un promedio anual de 3 millones de peces, pero desde 1970 han aumentado significativamente (hasta 9,6 millones en 1974). Este reciente aumento de las capturas se ha atribuido a la mejora de las tecnicas utilizadas en el programa de propagación artificial del salmón chum.

Las dos principales regiones del Japón donde existen poblaciones naturales de salmon son la isla de Hokkaido, y Honshu, la isla principal. La reproducción artificial del salmón se practica desde hace casi 100 años en el Japón, y constituye aún un instrumento importante para mantener el nivel de la población, en el que influyen negativamente los continuos cambios y la degradación del medio ambiente fluvial. De hecho, del 70 al 80 por ciento de los jaramugos de salmón que emigran de los ríos hacia aguas saladas proceden de viveros.

En el pasado, las salmonifactorías del Japón eran de propiedad privada, pero en 1934 todas las salmonifactorías de Hokkaido pasaron a manos del gobierno local, medida que ha permitido desarrollar un programa de reproducción del salmón bien coordinado en esa región. En trampas instaladas en los ríos se recogen los reproductores, a los que se hace desovar inmediatamente. En la mayor parte de los viveros, los

huevos se incuban en agua de pozo, a temperatura constante de 8°C. Anteriormente se soltaban los jaramugos inmediatamente despues de la absorcion de la vesícula vitelina, pero los experimentos hechos recientemente han mostrado que alimentando a los jaramugos durante 30 dias antes de la suelta se obtiene un notable aumento del indice de retorno de adultos. Se cree que este periodo adicional de cria antes de la suelta ha contribuido en forma significativa al reciente aumento (desde 1970) de las poblaciones de salmón chum. El promedio anual de produccion de jaramugos en los viveros de Hokkaido entre 1965–74 ha sido de 400 millones de salmón chum y de 11–140 millones de salmon rosado. El promedio de retorno de adultos procedentes de jaramugos de salmon chum liberados aumento del 1,08% en el periodo comprendido entre 1952–55 al 2 20% en 1966–69 Se ha calculado que los costos de produccion en vivero de un jaramugo entre 1962 y 1969 fueron de 1 65 yen (US$ ·05), y el costo de producción, en el mismo periodo, de un adulto que retorna se calculó en 126·2 yen (US$ ·42), o 36 1 yen (US$ 12) por kg. El valor de un salmón adulto en muelle es de unos 600 yen (US$ 1·98)

1 Introduction

Six species of Pacific salmon (*Oncorhynchus*) may occur in Japanese waters. Three of these, (red salmon, *O. nerka*; chinook, *O. tshawytscha*; and coho, *O. kisutch*) are rarely found here, but the other three are abundant and contribute to important commercial fisheries. Of these, chum salmon (*O. keta*) are the most important, followed by pink salmon (*O. gorbuscha*) and masu (*O. masou*).

The chum and masu are widely distributed and found north of Tokyo Bay on the Pacific and close to northwest Kyushu on the Japan Sea side. In contrast, the pink salmon is generally found only in northern and eastern areas off Hokkaido. Chum salmon generally reach maturity in three to five years with some maturing in two to six years. It takes two years for pink salmon to reach maturity. The masu salmon usually needs three years and in some cases four years to attain maturity.

As with all species of *Oncorhynchus*, both the male and female die after spawning. They commonly spawn on stream beds of pebbles and stones from September to January. The eggs of these fish hatch and develop into fry the following spring (March to June). Chum and pink salmon descend almost immediately to salt water. In contrast, the masu salmon remain in fresh water for a year and then migrate to the sea the next spring as smolt. Some of the fry of this species persist in fresh water without descending to the sea.

Although some regulations and conservation measures to protect fish resources were established during the Edo Era (1700–1800), it was not until 1888 and thereafter that technological measures for increasing salmon populations through artificial rearing started to develop. This technology expanded rapidly to become one of the main programmes of fish propagation in Japan.

Several difficulties inhibited the smooth development of this programme of artificial salmon hatching: failure to keep up with advancing industrial and land development; poor technology; failures in various experiments due to inexperience; and shortcomings caused by poor knowledge of applicable biological theories. However, in recent years, many of these problems have been overcome and the development of salmon rearing has attracted wide attention. There are few examples of this unique artificial development of a natural resource, and it is hoped that the Japanese experience may help pave the way to development of a rational means of proper resource conservation and management in other countries.

The purpose of this paper is to outline Japan's present salmon hatching and releasing practice in the Hokkaido and Honshu regions, with particular emphasis on the chum salmon propagation programme in Hokkaido.

2 Exploitation and migration of salmon

The long-term yearly fluctuations of chum salmon (*Oncorhynchus keta*) catches in Hokkaido Island are shown in Fig. 1.

During the early development stages of Hokkaido Island (1879–1893), the annual salmon catch varied between six and eight million fish, with the highest recorded catch of eleven million fish being made in 1889. This was followed by a lengthy period of poor production, with annual catches of only about three million fish. This occurred in spite of conservation measures introduced to protect and propagate the salmon resources. However, since 1970 there has been a significant increase in the annual salmon catches, and it is hoped that a stable catch of fifteen million fish annually can be achieved.

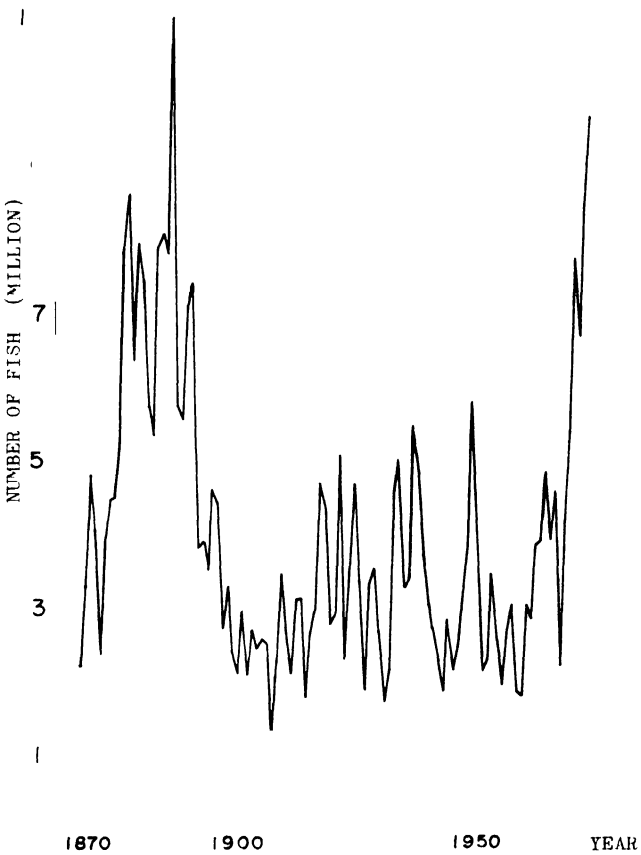


Fig 1. Annual fluctuation of catches of chum salmon in Hokkaido, 1870–1974

The annual fluctuations in catches of chum and pink (*O. gorbuscha*) salmon in Hokkaido from 1952–1974 are shown in Fig. 2. There was an increasing trend in harvest of chum salmon from 1952–1969, with catches varying from 1·7–4·7 million fish. Since 1970, however, there has been a progressive annual catch increase up to 9·6 million fish in 1974, the highest catch recorded since hatchery rearing of salmon was initiated. Pink salmon catches have followed more or less the same pattern of increased catches.

There are two races of chum salmon in Japan which are

identical except for their migratory behaviour. 'Autumn salmon' first appear in April–May in the southwestern region of the Alaskan Gulf, then migrate through the Bering Sea in June–July, and finally move south along the Kamchatka Peninsula and the Kurile island chain before reaching Hokkaido and Honshu in September–December (Fig. 3). Almost 90% of the 'autumn salmon' are harvested in coastal fisheries before entering their natal streams for spawning.

The 'summer salmon' migrate northward in April–August along the Pacific coast of northern Honshu and Hokkaido before entering their natal streams such as the Amur River tributaries and Okhotsk River in the USSR. Commercial catches of this population along the coast of Hokkaido have decreased appreciably in recent years.

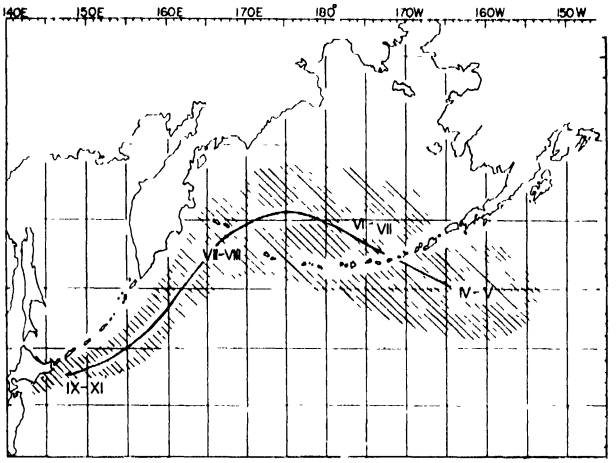


Fig 3. Estimated area of distribution and migration route of chum salmon originating from Japan (Kondo *et al*, 1965). Month is given in Roman numerals

3 Artificial salmon propagation programme

3.1 *History of hatchery development*

A knowledge of artificial salmon hatching had been introduced to Japan by 1876, but large-scale salmon propagation was not initiated until 1888 when the Chitose Central Salmon Hatchery Station was established at Chitose on a tributary of the Ishikari River. It was modelled after the Backsport Salmon Hatchery of Maine, USA.

By 1910, as many as fifty salmon hatchery stations had been built in Hokkaido. They were almost all privately owned, but there were a few public ones. At this stage certain difficulties arose in the management of hatcheries. Because of the fact that the profit from these hatcheries came from the sale of parent fish after they were stripped of their eggs, profits from the harvest were not necessarily reinvested in further development of the hatcheries. Consequently, hatchery activities were small in scale, and there was no appreciable increase in the salmon resource.

For this reason, most of the private hatcheries were taken over by the Hokkaido Government in 1934. This transfer of jurisdiction resulted in elimination of poor and ineffective hatching practices which had been carried out by non-governmental staff. Salmon propagation was incorporated into a national development programme in 1952 and at the same time administrative jurisdiction was transferred to the Fishery Agency in compliance with a newly established law on the conservation of fishery resources which took effect in 1951. Since then, the propagation programme has been conducted by the Government.

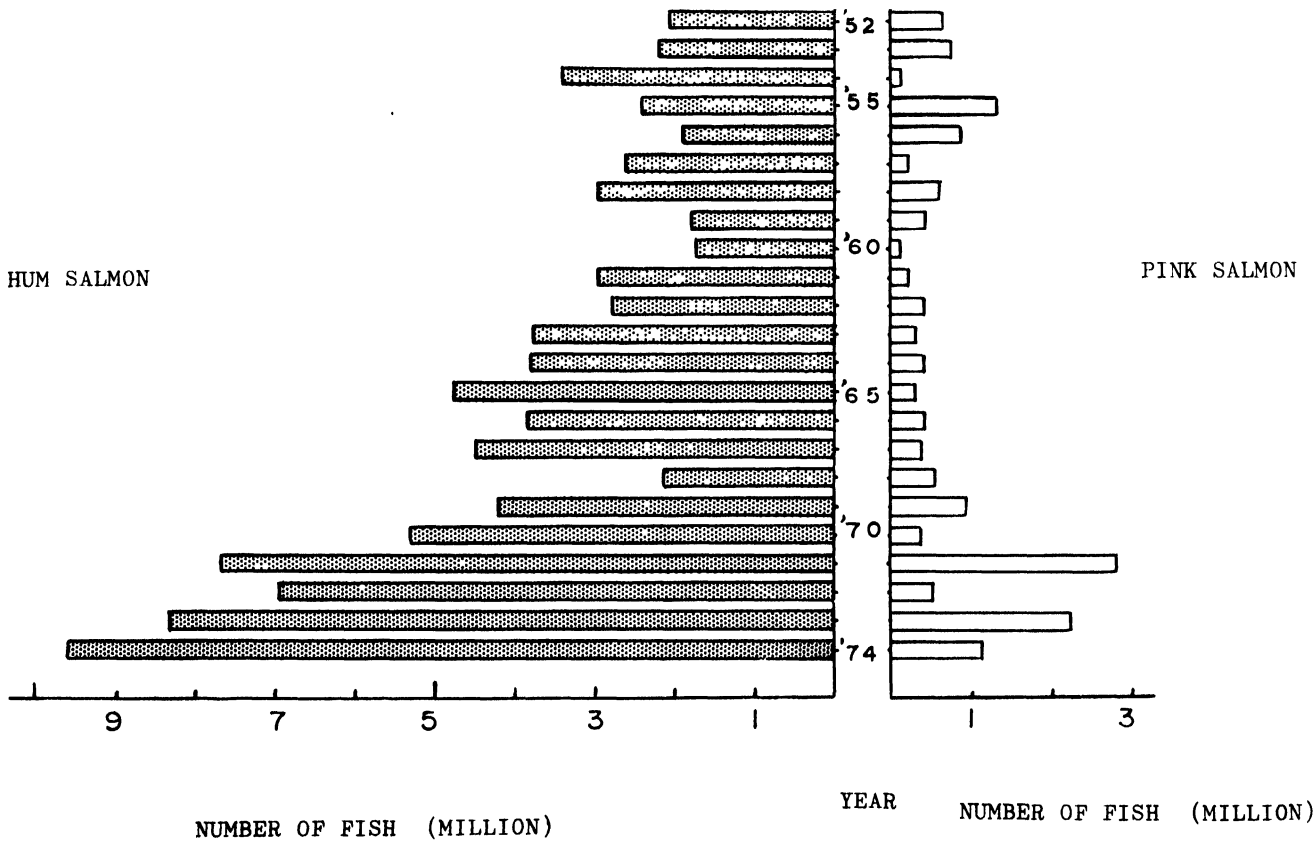


Fig 2. Annual fluctuation in catches of chum and pink salmon in Hokkaido, 1952–74

In contrast, development of salmon propagation in mainland Honshu followed a different pattern to that in Hokkaido. Initially, protection of natural spawning streams had been widely observed in the 1700s. The method of natural spawning protection in those days was commonly known as 'Tanegawa No Seido' (protection of parent fish). After the Meiji Restoration in 1867, the technique of artificial salmon hatching was introduced to Honshu and became widely adopted for increasing the salmon stock. Almost all the hatcheries were built by the private sector, and were managed by non-governmental units. Unlike Hokkaido, no state management has ever intervened and the management of hatcheries continues to be conducted wholly by private operations. In recent years, however, some governmental and prefectural subsidies have been granted to the hatcheries in Honshu in order to alleviate their financial burdens.

3.2 *Justification for artificial propagation*

There are about 200 rivers with salmon populations in Hokkaido. Of these, 123 rivers are currently utilized for salmon propagation purposes. Most of these rivers are relatively short, less than 50 km in length. There are only six rivers longer than 100 km, and 12 rivers are of intermediate size (50–100 km).

There are 37 national, two prefectural and 53 private hatcheries in Hokkaido. Artificial fertilization and subsequent control of salmon production in line with the propagation programme have been conducted, under guidance of the national hatcheries, at these stations. Various methods for increasing the stock have been adopted even at places where no hatcheries exist.

In Honshu, an artificial salmon propagation programme has been actively conducted in nine prefectures, particularly in the Tohoku or northern region. There are 111 hatcheries which are almost all run by private enterprises, with a few being operated by city and town authorities. In total, 111 rivers are currently used for propagation activities.

Water contamination has aggravated habitat conditions of salmon in both Hokkaido and Honshu. There are almost no rivers that are as pristine as they were in the early days. Further, environmental conditions have not improved to the extent that the salmon stock could be rehabilitated without any artificial intervention. Thus, various means of manipulating salmon populations become essential, and some measures have now been taken to help increase the resource. Efforts have also been made to overcome environmental deterioration.

As in other countries, major obstacles both to adult salmon moving upstream for their spawning migration and to fry descending the river after hatching include dams constructed for electric power generation, agricultural irrigation, flood control or forestry protection. In addition, there have been decreases and irregularity in the volume of flow in rivers as a result of de-forestation. Further, water contamination affects reproduction of salmon and degrades the environment. Environmental degradation is caused by gravel collection from headwater beds, riparian works, effluents from mining plants, waste water and sewage of urban areas, *etc.* It is difficult to protect the environment because development of socio-economic activities will, in one form or another, have some deleterious effect on water systems.

3.3 *Recent developments*

In order to ensure escapement of spawning adults to the rivers, every type of commercial fishery is prohibited in specific areas designated as protection zones along the coast and in estuaries of Hokkaido. In all the rivers, salmon fishing is prohibited except for collection of broodstock for artificial reproduction. About 70 rivers are currently used for this purpose.

Table I shows the changes in chum salmon propagation activities over the past 10 years. Recent catches in rivers average about 600 000 adult salmon. The lowest harvest during the period was 236 000 in 1968. After 1971, the ratio of spawning escapement to total catch has been declining gradually. This is contrary to the recent increase of the stock and the increased fishing effort along the coasts before the fish migrate upstream. The catch from rivers in Hokkaido is thought to represent the total spawning escapement as it is almost impossible for fish to escape capture in traps set in the rivers.

TABLE I

ANNUAL TOTAL CATCH (A), ESCAPEMENT (B), RATE OF ESCAPEMENT TO TOTAL CATCH (B/A × 100) AND NUMBER OF FRY RELEASED FROM 1965 TO 1974 FOR CHUM SALMON IN HOKKAIDO

Year	*Total catch*[a] *(millions)*	*Spawning escapement (thousands)*	*Rate of escapement (percent)*	*Number of fry released (millions)*
1965	4·75	806	17 1	549
1966	3 80	397	10 4	272
1967	4 50	597	13 2	435
1968	2 14	236	11·0	207
1969	4·17	578	13·8	362
1970	5 29	626	12 0	442
1971	7·65	855	11 0	576
1972	6·96	614	8·8	476
1973	8·32	594	7·2	445
1974	9·63	600	6 2	485

[a] Includes the coastal catch plus escapement

In Honshu, the number of chum salmon caught for hatchery use ranged from 108 000–245 000 during the same period, and the number of fry released varied between 109 and 271 million. Hatcheries in Honshu are generally small.

In order to attain satisfactory results from the artificial salmon propagation programme, it is necessary to secure a sufficient number of mature broodstock, obtain high quality eggs from healthy stocks, manage the subsequent incubation and hatching processes properly in order to produce vigorous fry, and release them at the right time and place to provide a high rate of adult return.

3.3.1 *Broodstock and egg collections.* To obtain eggs for the hatchery systems, adult chum salmon are trapped in streams using river racks and traps, seines, fish wheels and gillnets. The most common method is a river rack with a 'V' throated box trap across a stream. It is commonly called the 'Urai type' of fish trap (see Fig. 4).

Eggs are stripped immediately after the adults are caught, with non-ripe fish being kept in an enclosure until they reach maturity. Egg-stripping and subsequent artificial fertilization are conducted by the so-called 'dry method'. Eggs are first pressed from the female into an appropriate pan, and the sperm added and gently mixed with a soft feather. Fertilization takes place almost instantly when water is poured into the pan.

3.3.2 *Hatching and release of fry.* The fertilized eggs are



Fig 4. River rack with 'V' throated traps for catching adult salmon

incubated on trays until they hatch. Utmost care is taken in controlling water temperature, water flow rate, various diseases, *etc.* Fish in the early stages of their development are particularly vulnerable to physical stimuli. Therefore, a chemical disinfectant, *eg* malachite green, is commonly applied to the eggs through mixing with the water supply to prevent infection by *Saprolegnia* and other fungal diseases, instead of removing dead eggs.

The rate of egg development and hatching are primarily controlled by water temperature and differ from one species to another. In Table II the number of days required to hatch salmon under the natural conditions prevailing in Japanese streams is compared with the time required under constant water temperature as found in a hatchery. Spring water which is generally used in the salmon hatcheries is relatively constant in temperature, and it will be noted that its use materially shortens the period necessary for hatching as compared with that required in the changeable wild environment.

After hatching, the absorption of yolk generally takes approximately 60 days in spring water. Initially, hatchery fry were released at this stage into nearby streams. However, in order to minimize mortalities in the early stages of life, it was felt necessary to have more viable fry. Accordingly, the fry are now reared with artificial feed for about one month after yolk-sac absorption before being released. Artificial feed for fry is manufactured from a combination of fish meal (main component) and mineral and vitamin additives.

Wild salmon fry usually descend the streams in April–May. Hatchery-reared fry are released at the same time to synchronize their emigration with that of the wild fry populations. It is a unique feature of the salmon fishery in Japan that about 70–80% of the fry presently descending rivers to salt water every year have been reared artificially.

The fry of chum and pink salmon remain for a short time in estuarial areas until the water temperature exceeds 15°C around late June and early July. They then leave the coastal area for their offshore migration.

3.3.3 *Research related to hatchery propagation.* A number of studies have been conducted in Japan on salmonid reproduction in connexion with the artificial salmon propagation programme. These studies include work on homing migration, spawning behaviour, embryological development, the characteristics of fry, fluctuations in stock size and changes in environmental conditions.

In order to devise labour-saving techniques and achieve a high rate of adult return, various experiments on hatchery control and hatching devices have also been carried out.

It is hoped that these studies may contribute in the future to solving present problems and finding means to increase the stock size through high recruitment and assured production. Further solutions must also be found to offset environmental destruction in order to conserve this valuable resource.

4 Contributions of salmon through artificial propagation

4.1 *Effectiveness of the hatchery programme*

Two methods have been used to measure the effectiveness of the hatchery rearing programme:

(*i*) *Marking.* The contribution of hatchery fish to the returning adult population is measured on the basis of the rate of return of marked fry.

(*ii*) *Statistical analysis.* The contribution of hatchery fish to the whole population is measured by statistical analysis of the relationship between the number of fry released or number of salmon used for artificial spawning and the resultant number of returning adults.

The marking method is a reliable method of following the homing migration, and is widely used to study behavioural ecology of the fish, including migration and growth. Fin-clipping, one of the most popular marking methods, is mainly used for assessing improved techniques of release. It is also used to determine the appropriate time, place and method of releasing fry, and to examine the effectiveness of full feeding immediately prior to release. Application of various findings of marking experiments have contributed to the recent increases in salmon stocks.

In the following example, the relative effectiveness of artificial rearing in Hokkaido is examined using a statistical method.

TABLE II

NUMBER OF DAYS REQUIRED TO HATCH SALMON AT DIFFERENT WATER TEMPERATURES

Species	*Under constant hatchery conditions*			*Under natural conditions following spawning in streams*	
	Water temperature (°C)	*Number of days until hatching*	*Cumulative water temperature (°C) – degree days*	*Water temperature range (°C)*	*Number of days until hatching*
Chum salmon (*O. keta*)	8	60	480	7–8	120–150
Pink salmon (*O. gorbuscha*)	8	70	560–580	7–12	200–240
Masu salmon (*O. masou*)	8	55	440	7–12	210–230

The relationship between number of fry released and the resultant number of adult returns is shown in Fig. 5.

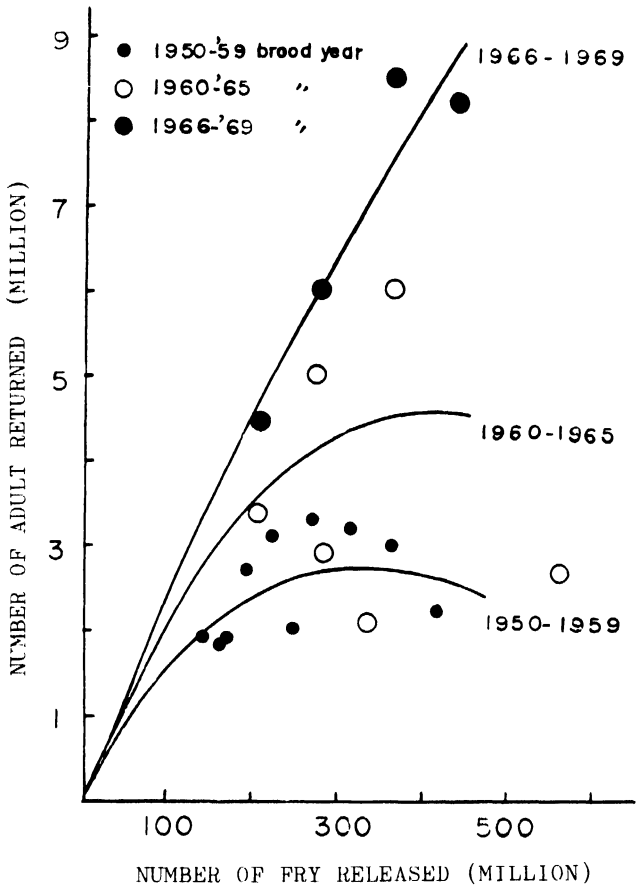


Fig 5 Reproduction curves for chum salmon of Hokkaido origin in the brood years 1950–1969

The number of adult returns for the brood years during the 1950–59 period was about three million compared with a release of 300 million fry; during the brood years of 1966–69, there were eight million returning adults compared with the release of 400 million fry. There have thus been significant changes in the results of the recent hatchery programme. The table below shows the change in rate of adult return as a percentage of fry released by selected brood year groupings in Hokkaido from 1952 to 1969:

Brood year	*Rate of return (percentage of fry released)*		*Number of adults returning per spawner*	
	Range	*Mean*	*Range*	*Mean*
1952–55	0·81–1 23	1 08	6·2–9 3	8 3
1956–60	0·51–1 67	1·09	4·1–12·9	8·4
1961–65	0·49–1·84	1 13	3 7–14 2	8·3
1966–69	1·89–2 41	2 20	14·9–18 6	17·0

It will be seen that the returns—whether based on percentage of fry released or numbers of adults returning per spawner—was markedly higher after 1966.

The recent increase in adult returns is attributed to the success of the chum salmon propagation programme in Hokkaido. Particularly, it is thought that the contribution of chum salmon stocks in Okhotsk and the eastern Hokkaido areas of the Pacific is substantial. The rate of return, for example, in major rivers such as the Abashiri and Shari Rivers flowing into the Okhotsk Sea has reached an unprecedented high level (4·3%) in recent years. High rates of return have also been observed at Shibetsu River in the same area. The spectacular development after 1966 is thought to have been caused by the initiation of fry-feeding and subsequent release of fry at an appropriate time.

The relationship between the rate of adult return and number of fry released after feeding is given in Fig. 6.

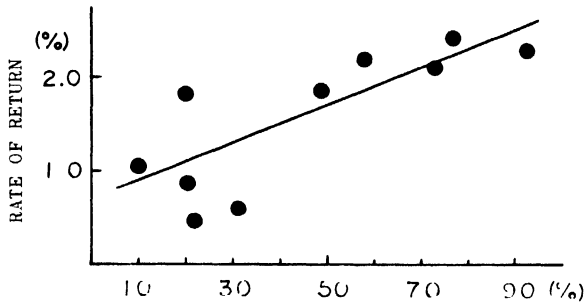


Fig 6 Relationship between rate of adult return and percentage of number of fry released after feeding in the population of chum salmon in Hokkaido

The relationship is expressed by the following equation:

$$Y = 0{\cdot}020X + 0{\cdot}695 \qquad (r = 0{\cdot}773)$$

where X is the percentage of number of fry released after feeding and Y is the resultant rate of adult return.

The increase in the percentage of fry fed with artificial feed before releasing seems to be responsible for the high rate of return. In other words, high rate of survival of the fry contributed to the resultant increase in the rate of return. It is not clear, however, whether such a high rate of increase will continue or not. If the productivity of the ocean can accommodate further increase of the salmon biomass, it will be possible to increase the size of salmon at stocking in Hokkaido.

4.2 *Economics of artificial propagation*

Almost all hatcheries in Hokkaido are owned and operated by the National Government. However, since stripped salmon are sold commercially, capture of fish and egg collection in many rivers are usually entrusted to fishermen's co-operatives, with the eggs being handed over to the hatcheries. In return for the service rendered by the Government, various beneficiary organizations make annual financial contributions to assist with hatchery operation expenses.

The total annual budget in recent years, including the governmental and private hatcheries, shows a sharp increase. For example, it was Yen 375 million in 1962 and Yen 670 million in 1967 (Japan Salmon Resources Preservation Association, 1975[1].

Production costs per fry and per fish returned for each brood year from 1962–69 are summarized below:

Brood year	*Production cost per fry (Yen)*[a]	*Production cost per fish returned (Yen)*
1962	1·33	128·0
1963	1·60	86·9
1964	1 48	239·5
1965	0·99	203 9
1966	1·74	79·2
1967	1·33	70·2
1968	2·90	125·6
Mean	1·65	126·2

[a] Fry production costs include cost of buildings and equipment, but exclude depreciation costs for hatchery facilities

[1] US$1·00 = Yen 303·0

The production cost of fry can be reduced if the catch of parent fish is high. Similarly, the production cost per returning salmon from artificially released stocks will be low. Should a high rate of return and low cost of fry production occur at the same time, the salmon fishery will prosper.

If the average weight of an adult salmon returned during the 1962–69 period was 3·5 kg, the mean cost per kg is estimated to be Yen 36·1. This is equivalent to 6% of the landed price per kg for adult salmon (Yen 600 on average). Since all chum are hatchery-produced, this shows that the present stock of chum salmon has been maintained by about 6% of all the value in the coastal catch of this species.

On the whole, the production cost per kg weight of salmon returned is thought to be a useful tool in estimating the relative effectiveness of the salmon-hatching and releasing activities which have been conducted in Japan.

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Atlantic Salmon Enhancement Techniques in Newfoundland

M. K. Farwell and T. R. Porter

Abstract

Natural straying, stocking with adults and stocking with fry produced in an artificial spawning channel and upwelling incubation boxes are being used to establish populations of sea-run Atlantic salmon (*Salmo salar*) within inaccessible watersheds of Newfoundland, Canada.

Fishway construction and natural straying of salmon has resulted in a gradual population increase in the Terra Nova River. Construction of a fishway along with the transfer of adults into Great Rattling Brook resulted in a more rapid increase in the establishment of an adult salmon population. The stocking of fry in Noel Paul's Brook from an artificial spawning channel (in which the mean annual egg to fry survival rate was 60%) resulted in an acceptable level of smolt production; the first adult returns indicated that a sea-run salmon population will become established. The initial stocking from upwelling incubation boxes (expected to yield over 80% egg to fry survivals) will take place in 1976.

Techniques de mise en valeur du saumon de l'Atlantique à Terre-Neuve

Résumé

On utilise des techniques de dispersion naturelle, d'empoissonnement par des adultes ou des alevins produits en chenal de fraye artificiel et dans des caisses d'incubation a courant vertical pour créer des populations de saumon anadromes de l'Atlantique (*Salmo salar*) dans les bassins hydrographiques inaccessibles de Terre-Neuve (Canada).

La construction des echelles à poisson et la dispersion naturelle des saumons ont provoque une augmentation progressive des populations dans le fleuve Terra Nova. La construction d'une échelle à poisson, jointe au transfert d'adultes dans le Great Rattling Brook, a accéléré la mise en place de la population de saumons adultes. L'empoissonnement de Noel Paul's Brook par des alevins provenant d'une chenal de fraye artificiel (dans lequel le taux de survie annuel moyen—de l'œuf a l'alevin—etait de 60%) a provoqué la production d'un nombre satisfaisant de saumonneaux; les premières remontees d'adultes ont montre qu'une population de saumons anadromes pourra s'etablir. L'empoissonnement initial après incubation en caisses à courant vertical (dont il est prevu que le taux de survie—œuf à alevin—depassera 80%) aura lieu en 1976.

Técnicas utilizadas para la difusión del salmón del Atlántico en Terranova

Extracto

Para introducir poblaciones de salmón anádromo del Atlántico (*Salmo salar*) en cuencas hidrográficas inaccesibles de Terranova (Canadá) se aprovechan las migraciones naturales y se siembran salmones adultos y alevines producidos en un canal de desove artificial y en cajas de incubación con corriente ascendente.

La construcción de rampas salmoneras y los movimientos migratorios naturales de los salmones han determinado un aumento gradual de la población en el rio Terra Nova. La construcción de una rampa salmonera y la transferencia de adultos ha permitido acelerar el establecimiento de una población adulta de salmón en el arroyuelo Great Rattling Brook. La siembra en el Noel Paul's Brook de alevines procedentes de un canal de desove artificial (en el que la media anual de supervivencia de huevos a alevines fue del 60%) se tradujo en un nivel aceptable de producción de jaramugos, y los primeros regresos de salmones adultos indican que se afianzará en esa cuenca una población de salmón anádromo. La primera siembra de alevines procedentes de tanques de incubación con corriente ascendente (que se espera permitan obtener una supervivencia de huevos a alevines de más del 80%) tendrá lugar en 1976.

1 Introduction

Stream investigations have indicated that 35% of insular Newfoundland's watershed, which has suitable rearing and spawning habitat for anadromous Atlantic salmon (*Salmo salar*), is not in production because of natural or artificial barriers. It has been estimated that the inaccessible stream areas could potentially produce an additional 1·4 million smolts or 170 000 adult salmon if these rivers were made accessible and anadromous populations were established.

The first type of enhancement project used in insular Newfoundland was the opening of inaccessible areas by the construction of fishways. From 1954 to 1975, 11 fishways were constructed. Three enhancement techniques are being used to establish anadromous salmon populations upstream from the fishways; namely, natural 'straying' from existing downstream populations, stocking with adults, and stocking with fry. The relative merits and efficiencies of each are discussed.

2 Results and discussion

2.1 *Fishways*

A fishway, constructed at a 12 m falls, 23 km upstream of the mouth of Terra Nova River began operation in 1955 (Fig. 1). The fishway was designed to provide sea-run salmon with an additional 414 km^2 of river drainage area. An upstream migrant counting trap at the fishway has been operated for the past 21 years and has allowed the annual magnitude of adult movement to be recorded (Fig. 2). In the initial five years (one life cycle) of operation, an average of 65 fish (range 10–140) per year were counted. These were 'strays' and were fish which, without the fishway, would have had to spawn within the lower portion of the river. For each of the second, third, and fourth life cycles there was a mean annual increase of 159, 171, and 118 salmon respectively from the preceding life cycle.

To determine if this increase was caused by enhanced production in the upper stream or merely redistribution of the existing run from the lower river, the counts of salmon at an existing fishway at a partial obstruction 15 km below the new one, and the angling catch on the river, were examined. The mean annual escapement through the lower fishway, for each five-year life cycle, from 1960 to 1974

has increased from 527 to 946 salmon (Fig. 2). During the same period, the mean annual angling catch for each life cycle has increased from 142 to 384 salmon (Fig. 2). It is concluded that the upper fishway has increased the Atlantic salmon production of the Terra Nova River by about 1 000 fish in approximately 20 years. This increase is directly attributed to expanding the amount of habitat accessible to Atlantic salmon by construction of a fishway and to natural propagation by stray salmon from an existing population downstream from the fishway.

2.2 *Fishway and adult stocking*

Beginning in 1957, with the development of a hydro-electric station on Rattling Brook, Bay of Exploits, the entire adult salmon run to this brook was collected and transported 56 km to Great Rattling Brook (Fig. 1). This is a tributary of the Exploits River with a drainage area of 1 658 km^2. The transfer was carred out each year for seven years (1957–63). During this period the number of salmon transferred ranged from 18 to 786 adults per year with a mean of 385 (Fig. 3). All fish were released upstream from an impassable obstruction 8 km from the mouth of Great Rattling Brook.

A fishway was constructed at the obstruction and was in operation in 1960, two years before any significant return from stocking could be expected. In 1960, 103 stray salmon ascended the fishway; this is comparable to the first few years of stray salmon through the upper Terra Nova River fishway. The total mean annual number of salmon above the Great Rattling Brook Fishway during the first five years of stocking was 636 fish, composed of transferred and stray salmon.

In 1961, the escapement through the fishway increased

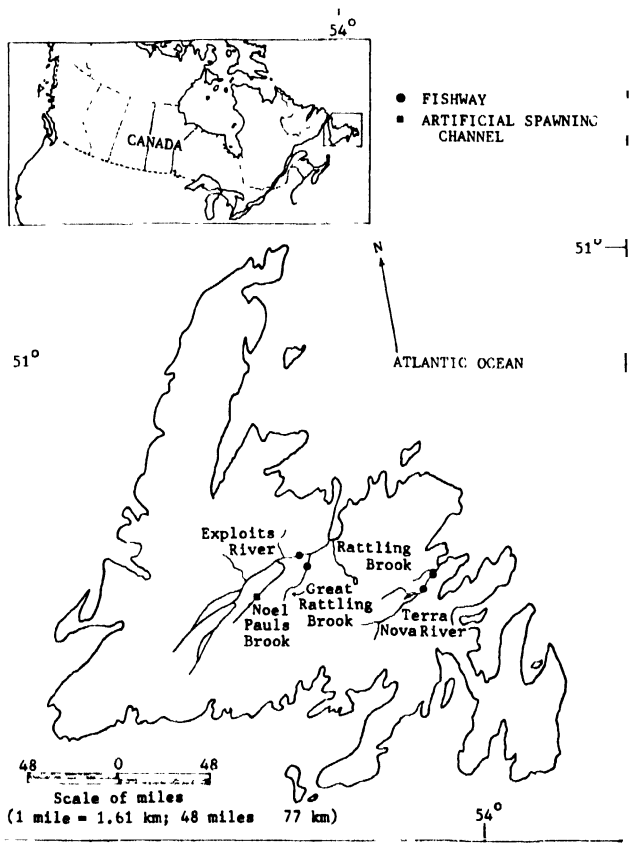


Fig 1. Newfoundland showing location of fishways and spawning channel

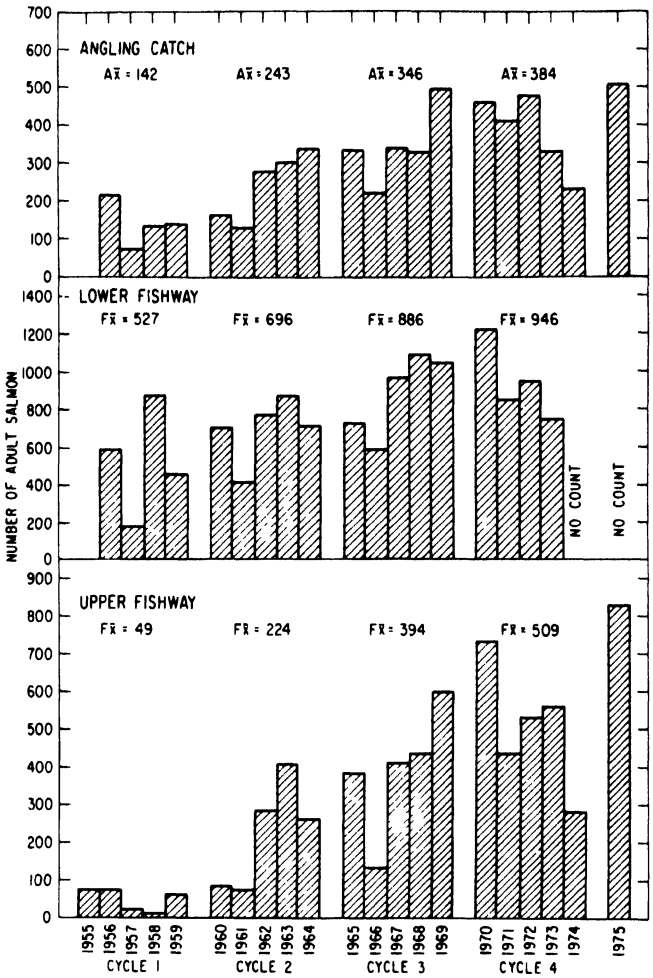


Fig 2. Adult Atlantic salmon counted through the upper and lower fishways and angling catch, 1955–75, on Terra Nova River Fx̄ is the mean annual count for each life cycle; Ax̄ is the mean annual angling catch for each life cycle

to 372 fish. Presumably, about 100 of these were strays and the remaining 272 were from two-year-old smolt. During the first cycle of returns (1962–66) from the adult transfer there was a significant increase in the salmon escapement. The mean annual salmon count at the fishway was 1 131 (Fig. 3). This indicated a mean annual increase of 495 fish. Similarly, during the second life cycle (1967–70) there was a mean annual increase of 227 fish. The mean annual number of returning salmon was 1 358. The third life cycle (1972–76) cannot be assessed; salmon were not enumer ated in 1973 and 1974. However, an escapement of 6 556 salmon was recorded in 1975. Thus, the run past the fishway increased from 103 in 1960 to 6 556 in 1975.

Because of the limited area available to salmon below the fishway, it is concluded that the stocking of adult Atlantic salmon in the newly accessible habitat of Great Rattling Brook increased the total production of this river by 2 500 fish within 6 years after the initial transfer.

It appears that the rate of enhancement of the Atlantic salmon production in Great Rattling Brook is three times greater than that of the Terra Nova River salmon population.

2.3 *Artificial spawning channel and incubation boxes*

The Exploits River, the largest river in Newfoundland,

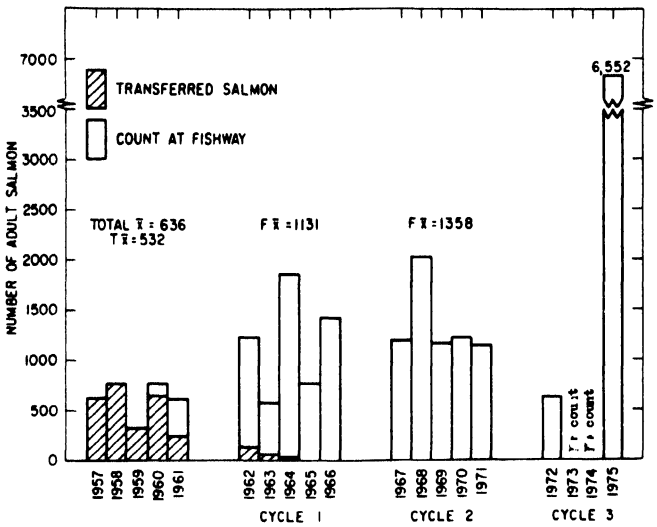


Fig 3. Number of salmon transferred to Great Rattling Brook and the escapement through the fishway, 1957–75. $T\bar{x}$ is the mean number of fish transferred, 1957–61, $F\bar{x}$ is the mean annual count for each life cycle



Fig 4 Artificial spawning channel, Noel Paul's Brook

accounts for about one third of the inaccessible salmon habitat in Newfoundland (Fig. 1). A fishway at Grand Falls, on the lower portion of the Exploits River, was constructed in 1974 and has made Noel Paul's Brook and adjacent tributaries accessible to sea-run Atlantic salmon. Establishment of a population of salmon was hindered by the shortage of broodstock; hence a more efficient use of available adult spawning stocks has been investigated. For successful adult transfer, large numbers of salmon are desired because of the relatively low egg to fry survival (10–20%) in naturally spawning populations. Considering these limitations of fish numbers, an artificial spawning channel, designed to increase egg to fry survival, was constructed on Noel Paul's Brook in 1967 (Fig. 4). The spawning riffles in the channel consist of gravel 1·3–7·6 cm in size. The water velocity is maintained at approximately 0·3 m/sec and the depth of the riffles is maintained at 20–25 cm. These characteristics conform to those selected by salmon spawning in an experimental channel in Newfoundland (Pratt, 1968).

Studies have shown that the optimum Atlantic salmon female density is one female per 2·5 m^2 of spawning gravel or 837 eggs deposited per m^2. The natural egg deposition capacity of the spawning channel is established at approximately 800 000 eggs. Under these conditions the mean annual egg to fry survival rate was 60%.

The fry, upon emergence, are collected, enumerated and distributed to selected sections of the main river and tributaries of Noel Paul's Brook. These sections are selected on the basis of suitability for natural rearing habitat and, if possible, stocked at the standing crop level of resident fish determined prior to fry stocking.

The standing crop of salmonids, as determined by electrofishing in Noel Paul's Brook, increased substantially after stocking with salmon fry. Downstream migrating smolt were enumerated on the lower section of Noel Paul's Brook to monitor smolt production. In 1970, one year prior to expected anadromous smolt migrations, approximately 1 000 fish were counted (Fig. 5). Ageing analysis indicated that approximately 90% of these were landlocked salmon. In 1971, 1972 and 1973 the number of smolt migrants increased to 6 200, 6 500 and 10 000 respectively. In 1974 the washout of a counting fence resulted in an incomplete count and only 5 000 smolts were enumerated. Adult salmon returns from the first three years of smolt enumerations were not monitored. However, the estimated smolt production for the first three years was 1·35, 1·90 and 1·94 smolts per 100 m^2 of stream area stocked with fry. This is similar to the smolt production per 100 m^2 of parr rearing area found in other Newfoundland streams. Thus, stocking with fry from a spawning channel

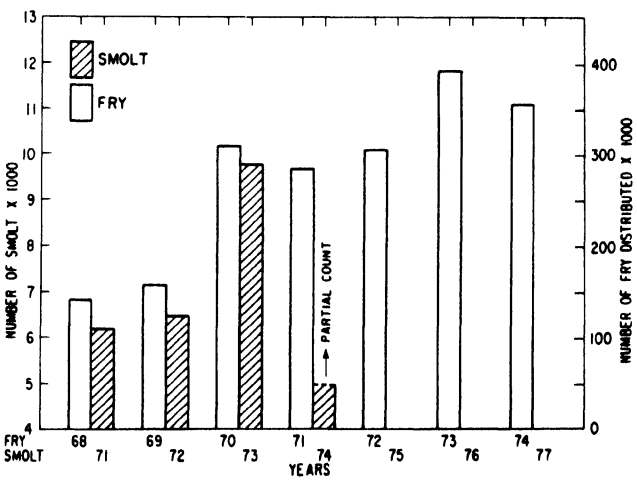


Fig 5. Salmon fry distributed and subsequent smolt production in Noel Paul's Brook

rapidly established a population of juvenile anadromous Atlantic salmon. The return of 360 salmon to the Grand Falls fishway on the Exploits River in 1975 indicated that there are fish returning to this previously unused area. The first five-year cycle of adult returns are necessary to estimate the rapidity of population establishment using a spawning channel. It appears however, that the use of Atlantic salmon spawning channels and subsequent fry stocking are biologically successful enhancement methods when limited broodstock is available.

With the need to expand stocking of other tributaries of the Exploits River, gravel incubation experiments using manual planting methods and upwelling incubation containers similar to those designed by Bams (1970) were investigated. The upwelling incubation system was decided upon as being the most practical and least expensive. Two incubation boxes were built in 1975 (Fig. 6). The preliminary egg loading of 500 000 in each box brought the total production potential of the Noel Paul's site to 1·8 million eggs. It is expected that the boxes will yield over 80% egg to fry survivals. Future studies to increase the carrying capacity of the upwelling boxes are pending. If the egg survival in the boxes is as high as expected, this would economically be a more feasible fish culture technique than the use of a spawning channel.

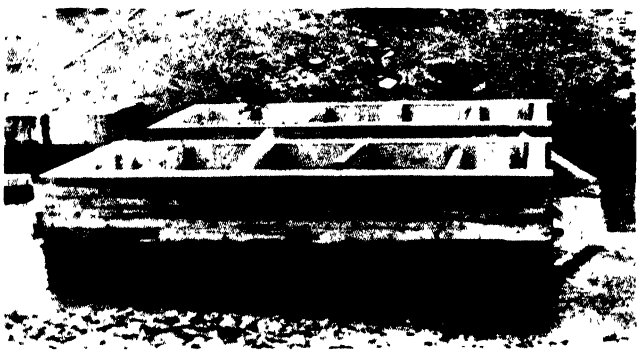


Fig 6. Upwelling incubation boxes, Noel Paul's Brook

3 Summary

Habitat inaccessible to Atlantic salmon in Newfoundland is being made accessible by the construction of fishways. Several techniques were used to establish salmon populations upstream from fishways.

(*i*) Natural straying of salmon resulted in an increase in the production of Atlantic salmon by 1 000 fish within 20 years.

(*ii*) Stocking an upstream river system with adult salmon resulted in a production increase of 2 500 fish within 6 years.

(*iii*) An artificial spawning channel increased the production of fry from a given number of spawners. The stocking of these fry indicated that anadromous populations can be established more rapidly by fry stocking than by stocking with adult spawners.

(*iv*) Upwelling incubation boxes are expected to pro duce a higher egg to fry survival (over 80%) than the present artificial spawning channel (60%). This should result in the most rapid population enhancement technique presently being investigated in Newfoundland.

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Stocking of Ayu, *Plecoglossus altivelis*, in the Rivers of Japan

R. Ishida

Abstract

Rivers in Japan have been stocked with fry of the salmonid fish, ayu (*Plecoglossus altivelis*), for over 60 years. At present, about 450 tons of ayu fry are caught annually and about 60% of these are used for river stocking.

Despite deterioration of riverine environment in Japan (through barriers to fish migration, pollution, *etc*) the annual catch of adult ayu is increasing. This increase is credited to the fry stocking programme. The rate of recapture, which is primarily by angling, varies from less than 10% to more than 80% with a mean rate of about 50%. Factors influencing the high rate of recapture include: the ayu's life cycle of only one year (including a journey to and return from the sea), its territorial behaviour, and its diet of diatoms (hence it does not compete with other species).

Three types of fry are used for stocking: a lake form (mostly from Lake Biwa and constituting most of the stocked fish); a river-run form (those ascending from the sea); and a sea-run form. After capture, sea-run fry must be conditioned to fresh waters and medicated during transport. The fish attain a length of about 20–22 cm by 30 September, five months after stocking; their period of maximum growth is usually in May and June.

At present, the supply of fry is unstable and the demand exceeds the supply. Demand increases as the number of anglers increases and as more ayu are required for cultivation as food. The yearly output of cultured ayu in Japan rose from 1 547 tons in 1969 to 5 927 tons in 1971. The situation may worsen if developmental plans for Lake Biwa (now producing more than 70% of the total supply of fry) result in destruction of spawning grounds through lowered water levels.

A solution to the problem of providing more fry may lie in: (*i*) greater utilization of the sea-run form; and (*ii*) artificial hatching and rearing of fry coupled with better stocking procedures.

Empoissonnement des rivières japonaises en ayus, *Plecoglossus altivelis*

Résumé

L'empoissonnement des rivieres japonaises avec des alevins d'ayu (*Plecoglossus altivelis*) un salmonidé, remonte à plus de soixante ans. A l'heure actuelle, l'on capture annuellement quelque 450 tonnes d'alevins d'ayus, dont 60% sont utilises pour l'empoissonnement des cours d'eau.

Malgré la détérioration du milieu fluvial au Japon (barrages s'opposant aux migrations des poissons, pollution, *etc*), les captures annuelles d'ayus adultes s'accroissent. Cet accroissement est imputable au programme d'empoissonnement par alevins. Le taux de recapture, qui provient essentiellement de la pêche à la ligne, varie de moins de 10% à plus de 80%, avec un taux moyen de quelque 50%. Les facteurs qui agissent sur le taux élevé de recapture sont notamment les suivants: le cycle biologique de l'ayu qui n'est que d'une annee (y compris l'avalaison et la remonte), son comportement territorial et son regime alimentaire à base de diatomées (absence de competition avec d'autres espèces).

Trois types d'alevins servent à l'empoissonnement: une forme lacustre (provenant surtout du lac Biwa et constituant la plus grande partie des poissons de peuplement); une forme fluviale (poisson de remonte); une forme marine. Après sa capture, la forme marine doit être adaptee aux eaux douces et faire l'objet d'un traitement pendant le transport. L'alevin atteint une longuer de quelque 20–22 cm au 30 septembre, 5 mois après l'empoissonnement; la période de croissance maximale se situe d'ordinaire en mai et juin.

A l'heure actuelle, l'approvisionnement en alevins est irrégulier et la demande excède l'offre. Cette demande augmente par suite de la multiplication des pêcheurs et parce que l'on a de plus en plus besoin d'ayus pour l'élevage aux fins d'alimentation. La production annuelle d'ayus d'élevage est passée de 1 547 tonnes en 1969 à 5 927 tonnes en 1971. La situation pourrait se dégrader si les plans de développement du lac Biwa

(responsable actuellement de plus de 70% de l'approvisionnement total en alevins) provoquent une baisse des niveaux d'eau aboutissant à la destruction des frayères.

Pour accroître l'approvisionnement en alevins on peut recourir aux solutions suivantes: (*i*) une plus grande utilisation de la forme marine; et (*ii*) l'éclosion artificielle du frai et l'élevage des alevins assortis d'une amélioration des procédures d'empoissonnement.

Siembra de ayu, *Plecoglossus altivelis*, en los ríos del Japón

Extracto

En los ríos del Japón vienen sembrándose jaramugos del salmónido ayu (*Plecoglossus altivelis*) desde hace más de 60 años. En la actualidad se capturan anualmente unas 450 toneladas de jaramugos de ayu, el 60% de los cuales se utilizan para repoblar los ríos.

A pesar del deterioro de los ambientes fluviales en el Japon (barreras a la emigración de los peces, contaminación, *etc*), la captura anual de ayu adulto va en aumento. El incremento se atribuye al programa de siembra de jaramugos. El índice de recaptura, sobre todo con caña, varía de menos del 10% a más del 80%, con un promedio del 50%. Entre los factores que influyen en el elevado índice de recaptura figuran, el ciclo vital del ayu, de un solo año (incluido el desplazamiento al mar y el retorno), su comportamiento territorial, y su dieta de diatomeas (en la que no compite con otras especies).

Para la repoblación se usan tres tipos de jaramugos: una forma lacustre (procedente sobre todo del lago Biwa, que representa la mayor parte de los peces sembrados); una forma de río (los que suben por los ríos desde el mar), y una forma de mar. Después de la captura, los jaramugos anádromos tienen que adaptarse a las aguas dulces y es necesario tratarlos con medicamentos durante el transporte. Los jaramugos alcanzan una longitud de unos 20–22 cm para el 30 de septiembre, a los cinco meses de la siembra; su período de crecimiento máximo es en mayo y junio.

En la actualidad, el abastecimiento de jaramugos es irregular y la demanda excede a la oferta. La demanda aumenta con el número de pescadores de caña y con el aumento de las peticiones para cultivarlo para consumo directo. La producción anual de ayu cultivado en el Japon ha aumentado de 1 546 toneladas en 1969 a 5 927 en 1971. La situación pudiera empeorar si el plan de desarrollo del lago Biwa (del que en la actualidad procede mas del 70% del abastecimiento total de jaramugos) resultara en una destrucción de los frezaderos a causa de una disminución en el nivel del agua.

La solución al problema de conseguir mas jaramugos podría consistir en: (*i*) aprovechar mejor la forma anadroma; y (*ii*) incubación artificial y cría de jaramugos, unido al empleo de mejores sistemas de siembra

1 History of stocking ayu in Japanese rivers

The ayu, *Plecoglossus altivelis* (a salmonid fish of the family Plecoglossidae), is widely distributed over Japanese territory from the southern tip of Kyushu island to the middle latitude of Hokkaido island. It has been a popular object of river fishing and highly relished as a food since ancient times. The long history of ayu fishing has resulted in a number of quite different fishing methods, such as 'Ugai', a traditional method now mainly retained for sightseeing purposes, and 'Tomozuri', angling with rod and line using a live fish.

The ayu has topped all other fish in Japan's yearly catch from inland waters for the last twenty years, accounting for 20–30% of the total catch. Individual fishery co-operative associations for Japanese rivers are, therefore, particularly interested in increasing the ayu population. The most popular method used for this purpose is stocking with wild fry. As compared with the stocking of other fish species, ayu repopulation is rather unique in that, generally speaking, almost no reproduction is expected from the stocked fish and those fish which survive are generally recovered as adults during the year of release. The reason lies in the ayu's unique life history. Its life span, involving a journey to and return from the sea, is completed within a year. In addition, ayu stocking is characterized by a high rate of recapture. There are several reasons for this: the ayu is a one-year fish; it rarely competes with other species of fish in its feeding since it eats diatoms; and it always behaves as the dominant species in the river since its individual members are strongly territorial.

In the past, Lake Biwa was the main source of supply of ayu fry for stocking. This source was established by Dr. Chiyomatsu Ishikawa in 1913 when he stocked the River Tamagawa in Tokyo with ayu fry from Lake Biwa on the assumption that the small ayu that are so abundant in that lake are actually land-locked fry that have almost no growth because of a lack of feed there. His results were favourable, and since about 1921 his method has rapidly spread over various districts in Japan. At a later date, fry caught in the sea and in rivers were added to the fry from Lake Biwa for use in stocking.

2 Present status of ayu stocking

Many major rivers in Japan are divided into sections by dams, so that the ayu is often prevented from ascending them, and its living area is being gradually reduced. Dams constructed in the upper reaches for the generation of power and for the adjustment of water level, change the aquatic environment in the upper and middle reaches, thereby diminishing the area suitable for ayu. Meanwhile, dams that are constructed in the lower reaches for irrigation and for industrial use block the ayu's upstream migration. In addition, water pollution worsens the situation. Table I, which shows a sharp decline in the ayu shipped from the River Tone, provides an example of such a situation.

Nevertheless, even in the face of deterioration of riverine environment, the total catch of ayu in Japan has continued to increase year after year as shown in Table II. For example, the yearly catch in the seventies is five or more times that in 1949. The practice of ayu fry stocking has largely contributed to this increase.

Table III compares the yearly catch of ayu with the number of fry released. The relationship between fry releases and corresponding catches of adults has a correlation coefficient of 0·89, which is significant at the 99% confidence level. This correlation coefficient is significantly higher than that for similar data for other major fish species.

About 447 tons of ayu fry are caught yearly (average catch, 1969–71). About 60% of these are used for stocking rivers.

3 Stocking practices

3.1 *Origin of the fry*

Ayu that have grown up in the river descend to the lower reaches to spawn. The fry that hatch there then enter the sea to spend the major portion of the fry stage in the littoral area. In spring they approach the shore. The fry which are caught there are called the sea-run form. At a more mature stage, the fry start to ascend the river; these fry are known as the river-run form. However, the designation 'sea-run

TABLE I
SHIPMENT OF AYU FROM THE RIVER TONE

Year	*1955*	*1956*	*1957*	*1958*	*1959*	*1960*	*1961*	*1962*	*1963*	*1964*
No. of fry shipped	413 682	462 761	672 737	756 638	413 600	707 590	818 124	82 520	0	0

TABLE II
CATCH OF FISH IN RIVERS (TONS)

Year	Species						
	Land-locked trout	*Pond smelt (Hypomesus olidus)*	*Ayu*	*Common carp (Cyprinus carpio)*	*Crucian carp (Carassius carassius)*	*Uguiminnow*	*Eel (Anguilla japonica)*
1949	150	149	1 717	390	915	677	823
1950	137	54	2 712	1 202	1 397	597	980
1951	179	60	2 502	720	1 224	834	989
1952	227	38	3 779	696	1 326	975	1 205
1956	358	35	4 977	1 451	3 057	1 557	1 558
1968	1 063	66	8 511	2 750	3 668	2 809	2 389
1971	1 280	349	9 642	3 020	3 923	3 814	2 122
1972	1 431	160	9 084	3 005	3 877	3 757	1 972

TABLE III
CATCH OF AYU IN RIVERS COMPARED WITH THE NUMBER OF FRY RELEASED

Year	*1958*	*1959*	*1960*	*1961*	*1962*	*1963*	*1968*	*1969*
Number of released fry ($\times 10^3$)	73 090	75 170	74 335	83 155	85 833	85 570	252 518	296 130
Catch (tons)	6 716	6 918	6 860	7 648	8 707	7 184	9 217	10 329

form' is sometimes used as a joint name for both sea- and river-run forms when compared with the lake form of ayu fry described below.

Ayu fry which are landlocked in lakes are obviously called the lake form. However, since fry caught from Lake Biwa dominates this group, the designation 'ayu lake-form fry' is also used as a popular name of the fry from Lake Biwa alone. Some landlocked ayu fry are also caught from Lake Ikeda, Kagoshima prefecture, but they just meet the stocking demands from its neighbouring area.

When a river is stocked with fry, the lake form achieves the highest rate of survival, the river-run form the next highest. Furthermore, because of its strong territorial behaviour, the lake form is preferred for stocking rivers in which rod and line angling with live fish bait is the main fishing method.

Table IV gives total catches of fry of the lake, river-run and sea-run forms, respectively, for the periods of 1964–66 and 1969–71. As shown in the table, the total catch for the second three-year period increased about 1·5 times over that of the earlier three-year period. There was an especially remarkable increase in the catch of the sea-run form.

TABLE IV
CHANGES IN NUMBER OF FRY CAUGHT BY ORIGIN

Origin	*1964–66 (A)*[1]	*1969–71 (B)*[1]	*B/A (%)*
Lake Biwa	205 921	325 536	158
Rivers	58 460	51 138	87
Sea	39 173	70 128	179
Total	303 554	446 802	147

[1] Average number caught per year

3.2 *Fry conditioning*

Fry of the sea-run form must be held for several days after their capture so that the fish can adjust to changed osmotic pressure before transfer from sea water to fresh water. The fry of lake- and river-run forms must also be held for a time to separate them from other species and injured individuals and to empty their gut to facilitate safe transportation.

Use of a fishpond is recommended to condition the sea-run forms. These fry are initially placed in a pond filled with 1 part of sea water to 4 parts of fresh water, and then within a day or two switched to fresh water. Accommodation of fry in sea water with such a dilution is found to heal minor wounds inflicted during netting. They are then held 5–7 days before shipment as seed.

3.3 *Fry transport*

The container used for ayu fry transportation must be made of materials with no harmful constituents, and have a semi-tight closure to suppress movement of the medium during transportation. Dilute sea water (1 part of sea water to 4 parts of fresh water) is best suited as the transport medium. The water must be fully saturated with oxygen to meet the high oxygen consumption rate of fry.

It is believed that a medicated bath during fry transport will prevent or cure diseases resulting in a higher rate of survival after stocking. For medication, about 20 g of a furan-type agent (*eg*, monofuracin) or about 500 g of an antibiotic (*eg*, water-soluble tetramycin) is dissolved in a ton of water.

3.4 *Survival rate*

At the request of the Freshwater Fisheries Research Laboratory of the Fishery Agency, Tokyo, the individual fisheries experimental stations of 31 prefectures conducted a survey from 1950 to 1952 which resulted in a determination of the rates of recapture of ayu released in 43 rivers (see Table V for a summary of this survey). The rate of recapture differed widely depending on the type of river; it

TABLE V
FREQUENCY DISTRIBUTION OF THE RATES OF RECAPTURE OF RELEASED AYU FRY AS DETERMINED FOR 43 INDIVIDUAL RIVERS IN JAPAN, 1950–52

Rate of recapture (%)	*No. of rivers*
0–10	2
10–20	2
20–30	7
30–40	3
40–50	7
50–60	7
60–70	5
70–80	5
80–90	5
90–100	0

ranged from less than 10% to more than 80%. The rate lay between 40 and 60% for the majority of the surveyed rivers; the mean rate of recapture was about 50% (49·77 + 6·91%).

A river is usually closed to fishing for two or three months after it is stocked with ayu fry. The rate of recapture r is given by the following expression:

$$r = p \times f$$

where p is the rate of survival for the closed period and f is the angling rate for the fishing period.

p varies with the condition of the released fry and the environmental conditions in the stocked river. However, from experiments conducted on a branch of the River Tone for two years (1950 and 1951) in which the environmental conditions were relatively unchanged, the author calculated the survival rate based on a version of the DeLury formula, to give values of 49% and 66%, respectively.

According to data from the same experiments, f was estimated at approximately 85% and 80% respectively. In addition, 44–50% was reported for the range of f value for a relatively small river, the River Ugawa, in 1956, and 80–90% for the same river in 1957. In a large river, the River Yoshino, an f value of 47–52% was reported in 1960 and 1961.

3.5 *Growth of ayu*

The effectiveness of stocking ayu is determined both by the rate of recapture and by the fish's growth rate. The most direct factor determining the growth of released ayu fry is the river diatom production upon which the fry feed. Indirect factors include: density of released fry, competition of the fry with other species, weather conditions, and various other environmental factors.

Table VI gives several examples of the growth parameters of the fry, in length, calculated by fitting the data on fish growth from the aforementioned 1950–52 survey to the logistic curve. As indicated in the table, in most of the rivers which were surveyed, the fish reach a length of 20–22 cm on 30 September about five months after stocking. The inflection point of the growth curve, that is, the time of maximum growth, is reached in May or June in most of the rivers. This suggests that a river's diatom productivity, which is very dependent on the hours of sunshine, is an important factor in the fish's growth.

The River Kusari is an exception in that the growth curve inflection point appears to be significantly delayed. This river has a relatively high altitude and low water temperature, and it is considered that fry growth is affected accordingly by environmental conditions.

3.6 *Unsolved problems*

Today, the biggest bottleneck in stocking rivers with ayu fry is assurance of a sufficient supply of fry. Two major points must be considered.

(*i*) *Unstable supply*. The supply of fry varies considerably from year to year and depends largely on the catch from Lake Biwa, which accounts for more than 70% of the total supply (Table IV).

Table VII, which gives the annual shipment of fry from Lake Biwa from 1958 to 1967, indicates that there are considerable fluctuations from year to year. On the other hand, shipments of the sea-run form of ayu fry show a general tendency to increase although the catch within a fixed area does not always increase.

(*ii*) *Imbalance between supply and demand.* As mentioned previously (section 3.1), the catch of ayu fry for the 1969–71 period increased almost 1·5 times over that for the 1964–66 period, but the demand for the fry changed during the corresponding period (see Table VIII). Compared to the catch as given in Table IV, it is found that the demand in 1966 for ayu fry was 1·7 times the actual supply. Although the catch of fry has increased, the large gap between demand and supply remains unfilled; the

TABLE VI
GROWTH DATA FOR RELEASED AYU FRY

River release	*Year*	*Length (cm)*[1]	*Inflection point*	*Maximum growth rate*	*Length on 30 Sept. (cm)*
Nuro	1950	34·96	1 Aug.	0 1196	24·56
	1951	20·59	7 Jun.	0 2166	20·43
	1952	24·02	18 May	0·0990	21 71
Nakatsu	1950	17·57	3 May	0·1070	17·12
	1952	18·73	25 Apr.	0·1144	18·35
Hayakawa	1950	21·79	31 May	0·1734	21·36
	1952	19·44	—	0·0407	17·59
Kusari	1950	19·98	23 Jun.	0·1012	17·60
	1951	27·15	29 Jun.	0·0982	20.20
	1952	48·24	29 Sept.	0·1470	24·24
Sami	1950	22·29	14 May	0·1736	22·01
	1951	19·44	21 Apr.	0·1689	19·37
	1952	20·89	5 May	0·1725	20·73
Hattori	1950	23·31	24 Apr.	0·1426	22·84
	1951	23·78	17 May	0 1330	22·69
	1952	24·75	24 May	0·1839	22·73

[1] Theoretical maximum value calculated by the logistic equation
Note: Data were fitted to the logistic equation

$$y = L(1 + e^{a-bx})^{-1}$$

to give the values in the table.

TABLE VII
SHIPMENT OF AYU FRY FROM LAKE BIWA (TONS)

Year	*1958*	*1959*	*1960*	*1961*	*1962*	*1963*	*1964*	*1965*	*1966*	*1967*
Shipment	192	203	153	159	183	173	234	272	112	198

TABLE VIII
DEMAND FOR FRY OF AYU (KG)

Year	*1966 (A)*	*1971 (B)*	*B/A* (%)
River stocking	333 900	370 000	110·8
Culture	190 600	280 000	146·9
Total	524 500	650 000	123·9

demand in 1971, for example, was 1·5 times as great as the supply. Since the number of anglers is increasing steadily, and the number of fry that ascend the rivers from the sea is decreasing, the demand for fry to stock the rivers is also increasing. At the same time, the demand for ayu fry for aquaculture is increasing even more rapidly as more ayu are cultivated, *eg*, the yearly output of cultivated ayu in Japan rose from 1 574 tons in 1969 to 5 827 tons in 1971.

This situation of a growing imbalance between the demand and supply of ayu fry may become even more serious if a development project for Lake Biwa (the main source of fry) is implemented. Under plans for this comprehensive project, Lake Biwa will supply water to the neighbouring Hanshin industrial area of Osaka and Kobe. There is a danger that withdrawing water from the lake will lower the water level to the point where the ayu's spawning grounds will be destroyed.

At present, two solutions to these serious problems are to be considered: (*i*) utilization of the unused sea-run form of ayu fry; and (*ii*) artificial hatching and rearing of fry.

It was indicated in Table IV that the rate of increase in the yearly catch of the ayu fry is greater with the sea-run than with either the lake or river-run forms. Table IX shows the yearly increases in the catch of the sea-run form of fry by prefecture. An especially marked increase is shown in some prefectures, and in response to a questionnaire sent to 39 Japanese prefectures, 18 indicated that they were intending to use more sea-run form fry or were investigating the possibility of doing so.

With respect to the second solution, advanced techniques for the artificial hatching and rearing of the ayu fry have been developed recently. A number of fisheries experimental stations are now capable of hatching and rearing more than a million ayu fry. Basic experiments are also in progress to find the most effective ways of stocking rivers with artificially-propagated ayu.

In addition, it is expected that more efficient methods will be established to fit the stocking to the maximum productivity of individual rivers.

TABLE IX
SHIPMENTS OF THE SEA-RUN AND RIVER-RUN FORMS OF AYU FRY BY PREFECTURE

Prefecture	*Year*			
	1964	*1965*	*1966*	*1967*
Shizuoka	6 465	7 887	25 000	16 201
Miyazaki	9 600	12 011	16 000	10 402
Ehime	2 348	4 857	6 800	120
Kanagawa	1 921	1 213	4 800	2 397
Kagoshima	1 500	1 000	6 000	156
Wakayama	1 000	5 412	6 000	16 930
Yamaguchi	15 792	14 173	14 000	7 092
Tokushima	700	5 110	17 500	14 382
Kochi	400	—	400	750
Kyoto	500	6 500	7 900	1 100
Ibaraki	—	—	—	3 099
Aichi	—	—	—	2 390
Total	40 226	53 653	104 400	75 019

Chapter IX Nutritional Requirements and Feed Technology

Fish Nutrition and Fish Feed Manufacture

W. H. Hastings

Abstract
Data from research institutions and fish culture centres indicate that certain nutrient levels in fish feeds promote certain production results. In accordance with profit goals, efficiency targets are selected, and a table presented of nutrient amounts needed per kilogramme of food, per kilogramme fish gain and per kilogramme fish gain per day. Some techniques of feed manufacture are presented as guidelines in adapting prepared foods to the culture of various fishes.

Nutrition des poissons et fabrication d'aliments pour poissons
Résumé
Les travaux des institutions de recherche et des centres piscicoles révèlent que la présence d'un certain niveau de nutriments dans les aliments pour poissons permet d'obtenir certains résultats sur le plan de la production. Compte tenu des buts de rentabilité, le document détermine des objectifs de rendement et presente un tableau des quantités de nutriments nécessaires par kilogramme d'aliment, par kilogramme d'augmentation de poids des poissons et par kilogramme de gain pondéral des poissons par jour. Quelques techniques de fabrication des aliments pour poissons sont décrites à titre indicatif pour permettre d'adapter les aliments préparés à l'élevage de telle ou telle espèce de poisson.

La nutrición de los peces y la fabricación de piensos
Extracto
Los datos facilitados por instituciones de investigacion y centros de piscicultura indican que la presencia de ciertos niveles de nutrientes en los piensos para peces permite obtener determinados resultados de producción. Se presentan metas de eficiencia segun los beneficios que se desean obtener y se da un cuadro de las cantidades de nutrientes que son necesarias por kilogramo de piensos, por kilogramo de aumento del peso de la biomasa ictica y por kilogramo de aumento diario del peso de la biomasa ictica. Se indican algunas técnicas de fabricación de piensos, que pueden servir de directrices para adaptar los piensos preparados al cultivo de diversas especies de peces.

1 Introduction

Worldwide pressure to expand and develop aquaculture is motivated primarily by the need for increased protein supply. Its large-scale development depends, however, upon provision of adequate economic return from the investment and labour involved, and in this respect the cultivation of fish offers certain advantages over that of more domesticated land animals. One of these advantages is the ability of many species of fish to convert prepared feeds into weight gains more efficiently than do most terrestrial animals. Another is that ingredients in prepared fish feeds compete less for human use than feeds for terrestrial animals. For such reasons, the stocking with fish of ponds, tanks, 'tambaks' and other water bodies is common practice today.

It is estimated that over six million tons of finfish and shellfish are produced annually by world aquaculture. This amount could be greatly increased using the same space by selective breeding, improved water quality and optimal feeding. Only a beginning has been made in the selection of fish for intensive culture which will maintain maximum growth rate and high food conversion under conditions of low oxygen, high stocking density and the presence of other species.

Among the fishes cultured commercially using prepared feeds are: salmonids, carps, tilapias, catfishes, milkfish, tropical or ornamental fishes, eels, grey mullets, flatfishes and shrimps. Many other fishes are subjects of research and field testing as aquacultural stock.

Intensive fish culture implies stocking of impoundments at densities of up to two or more fish per m^2 surface of quiet water (as in ponds and tambaks), and up to 100–200/m^3 in circulating water in tanks and pools. Manufactured feeds are essential for economic use of time, space and aquacultural facilities. There are two major objectives in the use of manufactured foods: to provide nutrients for fish growth, and provide profit for the aquaculturist.

Qualitatively, the nutrient requirements of fish are the same as those of higher animals. Quantitatively, however, many different levels are used to optimize production of fish subject to variations in stocking density, initial age and weight, water temperature, water chemistry and management practices. In listing these requirements, the data reported by research laboratories and commercial fish farms may best be understood using examples of fish growth obtained by the ingestion of prepared feeds which meet certain nutrient targets. The following terms and values will be used in this paper:

- W_0 (initial weight) = 1 000 g
- W_t (final weight) = 2 000 g
- t (time in days) = 28
- r (specific growth rate) = 2·5% = $\mathrm{Ln}W_t - \mathrm{Ln}W_0/t$
- Food conversion factor = weight of food fed divided by fish gain in weight
- Dry feed – without moisture. Air dry – moisture content 10%
- Approximate analysis of fish = 75% water, 16% protein, 8% fat, 1% minerals
- Nutrient requirements are expressed as:
 - unit amount/kg fish gain
 - unit amount/kg food used
 - unit amount/kg fish/day

2 Nutrition targets

2.1 *Gross food conversion efficiency*

Gross food conversion efficiency is the percentage of food converted to fish flesh, on an equivalent weight basis. Calculated values in commercial aquaculture range from zero to 50%. Only in the utilization of the egg yolk by the embryo is gross food conversion efficiency found to be maximum. Lasker (1962), reported 77–79% efficiency in developing Pacific pilchard (*Sardinops caerulea*) embryos and sac fry.

Zero or low food conversion efficiency normally occurs as a result of:

(*i*) Insufficient feeding: (*a*) foods not ingested due to dissolution in water (*b*) foods unavailable due to competition (*c*) foods undigestible or with high digestive and metabolic costs;

(*ii*) Management stress: (*a*) heavy stocking density (*b*) excessive water movement as in raceways (*c*) feeding schedule or method not adapted to fish needs;

(*iii*) Physiological stress: (*a*) rapid gonadal development;

(*iv*) Environmental stress: (*a*) low dissolved oxygen (*b*) too low or too high water temperature.

Low food conversion efficiency also occurs when metabolic rate is slow or when all nutrients in a food are utilized for activity and subsequently converted into metabolic wastes.

A variety of foods ranging from natural foods to semi-purified diets tested by Brett (1971) showed gross conversion efficiencies from 10 to 40%. High conversion efficiencies indicate not only adequate nutrient content and nutrient balance, but good food acceptability, availability, digestibility and optimal environmental conditions during a period in the fish's life when metabolic demands are mostly for growth rather than for other activities.

A gross food conversion efficiency of zero is equivalent to a conventional 'food conversion factor' of infinity. A 20% conversion efficiency (a target for successful fish farming) is equivalent to a conversion factor of 1·39 or a dry food/wet fish gain factor of 1·25. Commercial fish farms, government hatcheries and research laboratories report food conversion factors of 1·8–1·0 which can be expressed as gross food efficiencies of 15–28%. By contrast, fast-growing poultry marketed at 2 kg have a gross food conversion efficiency of 12–16% and poultry egg production is attained with a food conversion efficiency of 10–12%.

Example I: 1 000 g of fish, converting food at a gross efficiency of 20%, will ingest 1 250 g food (dry weight) or 1 390 g air-dry food. At a specific growth rate of 2·5%, average daily intake would be 31·25 g dry or 34·8 g air-dry food.

2.2 *Energy*

Energy is essential in that it contributes to the utilization of all nutrients in a diet. It is measured physically as calories of heat and physiologically as change in body weight (gain or loss), oxygen consumption and metabolic activity. Gross food conversion efficiency and energy efficiency are closely related.

The differences between the energy content of ingested foods and that deposited as gain in weight represent losses because of indigestible food and the energy 'cost of living'. Feeding activity, nervous excitation, locomotion, food assimilation and metabolism are non-productive expenditures of energy. A good understanding of aquacultural procedures can increase the conversion of food energy to stored energy as fish weight.

Calorie values of food components are shown in Table I. Calculations in this paper use those values listed as 'For fish'. These are practical values of potential physiological energy under the conditions of an optimal environment and careful food selection and do not reflect net energy or digestibility. The same values will be used for food energy and energy stored in fish.

The energy efficiency for fish production as calculated from successful fish feeds is from 25 to 40%. This shows that less than half the total energy in food is used for growth and the remainder is expended on the 'cost of living' (Brett, 1970). It also indicates that energy *per se* is more efficiently used than food *per se*. This is because there are several components in foods that have no energy value, *eg*, water, minerals, fibre.

TABLE I
NUMERICAL VALUES OF ENERGY EXPRESSED AS KCAL/G

Nutrient	*Gross*	*Physiological energy*	
		For homeothermic animals	*For fish*
Protein	5 65	5·2	4·0
Fat	9 4	9·0	9·0
Raw starch	4·15	4·0	4·0
Sugars	4·15	4·0	4·0

Generally, foods less than 3 000 kcal/kg are low in gross food efficiency for they contain low fat and high fibre ingredients. High energy foods which contain high levels of fat and carbohydrate are high in food efficiency but often result in above average non-protein weight gains. A rule of thumb on gross physiological energy content in fish foods is to provide 8 kcal/g protein in the diet. This allows sufficient fat and carbohydrate to spare protein as an energy source and provides 'free energy', *ie*, that energy available for biological energy and growth.

Example II: 1 000 g of fish consisting of 160 g protein and 80 g fat have 1 350 kcal of production energy. Using a 'target' of 32% energy efficiency, total ingested energy must be 4 250 kcal and if gross food efficiency is 20% (Example I) with a conversion factor of 1·39, each kilogramme of food must contain 3 058 kcal. For a specific growth rate of 2·5% energy intake must average 106·4 kcal/day.

2.3 *Protein*

Fish show a wide degree of homeostatic control of body composition and capacity to digest and utilize foods of widely different materials. Protein levels in successful fish foods range from 20 to 60% to accommodate for differences in the physiological needs of different fishes. In their natural environment, milkfish (*Chanos chanos*) make a rapid transition from the absorption of egg yolk, a high nutrient density food, to a diet of blue-green and green algae (Myxophyceae and Chlorophyceae)—materials varying in protein from 10 to 20% (dry basis). Salmonids begin and continue throughout life on diets containing 40–60% protein.

The protein requirement is tied to the general energy requirement at a given water temperature and the fish's ability to gain weight at its inherent capacity. It is also related to size, age, and environmental stresses, such as stocking density, low dissolved oxygen supply, and the presence of toxicants. Rapidly growing chinook salmon (*Oncorhynchus tshawytscha*) in 8·3°C water attain optimum growth with a food containing 40% protein, whereas the same fish in water of 14°C attain optimum growth with a food containing 55% protein (DeLong, Halver and Mertz, 1958). At the lower water temperature, foods containing more than 40% protein produce stress due to an excess of ammonia released from the gills. Channel catfish (*Ictalurus punctatus*) show optimum growth at 20°C on a 35% protein diet, whereas at 25°C they show optimum growth on a 40% protein diet (Dupree and Sneed, 1966). For common carp (*Cyprinus carpio*) the optimum protein is 38% at 23°C (Ogino and Saito, 1970); and for eels (*Anguilla japonica*) 48% at 25°C (Nose and Arai, 1972).

In general, a lower protein level in a food results in greater efficiency of deposition as growth. There is, of course, a point of diminishing returns at which protein is

used mostly for maintenance energy and little is contributed toward growth. Salmonids on a 40% protein diet utilize about 30% for growth. Catfish on a 30% protein diet show a protein efficiency of about 40%. Gerking (1955), studying bluegill (*Lepomis macrochirus*) reported a maximum of 33–35% nitrogen retention in body weight with a trend toward more nitrogen retention, although at less efficiency, as dietary protein increased. In milkfish, ingestion of 100 g of food containing 20% protein (dry weight) resulted in a gain of 8 g of protein (Schuster, 1949; Hastings, 1975).

In order to utilize protein efficiently for growth, other sources of energy must be present in the diet. All fish have the ability to use fat and carbohydrate to some extent to spare protein as an energy nutrient. A typical response to added energy was reported by Mann (1974): rainbow trout (*Salmo gairdneri*) showed optimum growth on a low-fat diet containing 26·8% protein and increased growth by the addition of fat to a food containing 45·9% protein. Increased growth also required an increase in the vitamin concentration of the diet.

Prather and Lovell (1973) found that optimum growth for channel catfish was achieved with a 29% protein food when total energy was 2 200 kcal/kg and that increasing food energy to 2 860 kcal/kg permitted the fish to use a 42% protein food and attain considerably more growth.

Fish have the ability to handle protein in excess of that needed for growth and maintenance by deaminizing amino-acids branchially and excreting ammonia. This is sometimes a stress for fish in small impoundments. Hastings and Dupree (1969) tested foods for channel catfish stocked in aquaria and ponds. Using protein levels of 10–50% at 10% increments, it was found that in aquaria, fish attained maximum growth with 40% protein foods and that foods containing more protein depressed growth. In ponds, no maximum protein level was found and growth increased on all foods with increasing protein level, although to a lesser degree with foods exceeding 30% protein.

The various amino acids derived from protein and deposited in fish tissue are either fed or biosynthetized from the ten essential ones. (See Halver, 1976, for amino acid targets in fish foods.) Non-protein nitrogen has little or no value in fish tissue formation or protein synthesis in the fish gut, although its presence in food has shown an improvement in negative nitrogen balance at below maintenance protein levels. Peptide linkages may be essential for digestion and absorption in some fish (Halver, 1976), since they cannot maintain normal growth on mixtures of amino acids alone or on hydrolysates of complete proteins.

The essential amino acid pattern of proteins in fish foods has been determined for salmonids, catfish, eels and seabream. Arginine requirement for these fishes was found to be higher than for mammals, and tryptophan requirement less. Nose and Arai (1972) found that eels grew best on a gelatin-casein diet with the addition of 1% cystine which has a methionine-sparing function.

The gross conversion efficiency of each amino acid has not been determined but no doubt these will have individual values reflecting aquacultural needs and overall food composition.

Example III: Using a target for protein conversion efficiency of 35% (measured as protein gained divided by protein ingested), 1 000 g of fish growth containing 160 g protein would require 457 g protein in the food. With a gross food efficiency of 20% (conversion factor of 1·39), each kilogramme of food fed would contain 329 g protein or approximately 108 g protein per 1 000 kcal in food. At a specific growth rate of 2·5%, the daily protein needs per 1 000 g fish are 11·45 g.

2.4 *Fats*

Fats and oils are high energy components of prepared fish feeds. In most ingredients they are 85–90% digestible. Successful fish feeds contain from 4 to 18% fat. The gross conversion efficiency of fat as measured by gain in fish weight plus use as energy is approximately 90%.

Fat as an energy source has a protein-sparing action especially useful in foods for fry and young fish where protein needs for growth are at a maximum. There is evidence that fat and fatty acids have an additional role in providing a dietary source of essential fatty acids of the omega-3 series required for maximal growth and normal tissue deposition. For rainbow trout (*Salmo gairdneri*) linolenic acid (18:3ω3) will meet the fatty acid requirement at 0·8–1·0% of the diet or 1·66–2·7% of dietary energy (Sinnhuber, Castell and Lee, 1972; Watanabe *et al.* 1974). However, marine fishes, such as red seabream (*Pagrus major*) and turbot (*Scophthalmus maximus*) are apparently unable to convert linolenic acid to long chain polyunsaturated acids at rates needed for normal growth. These omega-3 fatty acids must, therefore, be supplied preformed in the diet (Yone and Fugii, 1975; Cowey, 1976).

Fats in fish food must be accompanied by sufficient choline, methionine and tocopherols for efficient metabolism. Fats altered by oxidation or hydrogenation may function as energy but not as sources of essential fatty acids. Further oxidation of fats in prepared feeds to aldehydes, ketones and acids may be toxic to fish and may accelerate the loss of certain vitamins present in foods. To avoid excessive oxidation of fats, antioxidants are recommended in prepared fish feeds, *eg*, alpha tocopherol (vitamin E) has antioxidant properties, and is used at levels of 500–1 000 IU/kg feed for this purpose.

Example IV: 1 000 g of fish weight gain using 1 390 g of air-dry food and meeting the target of omega 3 fatty acids, would contain approximately 4% of fish oil. (See Table 3, Fatty Acid Composition of Dietary Lipids in National Research Council, Subcommittee on Fish Nutrition, 1973.) It is also recommended that 2–6% fat should be added to the diet for a total fat content of 6–10%. For 1 000 g gain of warmwater fish with a food conversion factor of 1·39, the feed should supply a minimum target of 6% fat or 83·4 g containing 750·6 kcal; for coldwater fish the food should supply a target of 10% fat or 139 g containing 1 251 kcal[1].

Since additional energy to complete the energy target (Example II) must come from carbohydrates, the total energy budget is as shown in Table II.

2.5 *Carbohydrates*

Fibre, raw starch and polysaccharides are found in most prepared fish feeds. If their digestion occurs, products of hydrolysis are assimilated into the blood stream where their only known function is to provide energy. As such, they

[1] These targets are based on practical formulation of fish feeds. The amounts of fat are not rigid; much depends on its quality and source. Feed manufacture and storage are complicated by fat and therefore a maximum target may also be needed.

have a protein-sparing action and the excess is partially stored in the liver as glycogen and partially converted into visceral and muscular fat.

Carbohydrate refers specifically to the 'nitrogen-free-extract' portion of a feed and is calculated as the difference between 100% and the sum of protein, fat, fibre, fibre ash and moisture. It is considered physiologically digestible and, therefore, the amount in a food is assigned an energy value of 4·0 kcal/g. Carbohydrate is inexpensive energy compared to the cost of protein and fat for this purpose. The range of carbohydrate found in prepared fish feeds is 10–50% and the efficiency of utilization as energy varies from 40 to 99%.

Many fish adapted to herbivorous diets have cellulases and diastatic enzymes for rapid and efficient digestion of fibre and raw starch. By constantly grazing on algal pastures, milkfish (*Chanos chanos*) can utilize a diet high in fibre and carbohydrate and low in protein. Gross conversion efficiency of natural foods (Schuster, 1949) and of prepared feeds (Hastings, 1975) is estimated to be approximately 12% while a protein efficiency of 40% is attained. On the other hand, trout ingesting a natural diet of forage fish (Brown, 1957), show a gross food conversion efficiency of 16% and the same value for protein efficiency. With carbohydrate in a prepared trout diet, production is attained with much better efficiencies for both gross food and protein.

Levels of carbohydrate shown in Table II brought into the food to complete the energy requirement, are typical of amounts found in successful fish feeds, *eg*, about 20% in feeds for coldwater fish and about 30% in warmwater fish feeds. In addition to energy, carbohydrates have the physical functions of texturizing manufactured feeds and acting as a binder in the formation of both compressed and expanded pellets. After the nutrient requirements for protein, fat, vitamins and minerals are met, the ingredients most used as 'fillers' to complete the formula at 100% are cereal grain by-products, high in fibre and carbohydrate. The digestibility of the raw starch component of these ingredients is 40–85%. However, the manufacture of expanded pellets requires a formula which contains large amounts (up to 50%) of whole cereal grains to achieve floating properties. The high moisture and high temperature associated with this process results in almost complete starch gelatinization, greatly increasing its digestibility. When digestible carbohydrate is consumed in excess of energy requirements, it builds up into visceral fat deposits and fatty infiltration in organs, eventually restricting normal body functions.

2.6 *Vitamins*

Most of the nutrients known as 'vitamins' are required by fish. Commercial and test fish feeds contain these as a premix additive compounded by special formulation. Generally, the levels of vitamins in premixes are twice the amount determined as minimum for growth, with no allowances for the vitamin content of other ingredients. The requirements shown in certain publications (*eg*, NAS/NRC, 1973) allow for deterioration of vitamins during normal storage and for higher than average needs.

In most commercial premixes the B-complex vitamins are supplied from tested and guaranteed concentrations of fermentation products and in a sense may be considered biologically synthesized. The fat-soluble vitamins A, E, K and D, may be chemically synthesized or extracted from natural sources. The source of vitamin D_3 is often fish liver or body oils from fish which also provide vitamin A.

Because of the hygroscopic nature of choline chloride, this vitamin may be withheld from a premix and added to the food separately; however, this is not necessary for storage in a hermetically-sealed container over a short period. Ascorbic acid, which has been added to fish feeds only recently, is essential for young fish and fingerlings subjected to high population density, which causes nervous excitation and limited muscular movement. It is rapidly oxidized to the dehydro form which is still biologically active, but on further oxidation becomes biologically inactive. To avoid loss in processed and stored feeds, this nutrient may be added as a spray after manufacture or procured in the water-repellent form which protects it from chemical change, even during the process of expansion pelleting (Hastings and Simco, 1973).

The role of vitamins, deficiency symptoms and their content in various food ingredients may be found in several publications. Table III lists the levels required in fish foods using production targets shown in Examples I, II, III and IV and values calculated from Table IV in NAS/NRC (1973).

2.7 *Minerals*

For trout and carp, standard mineral salt mixtures used in test diets for laboratory animals have proved adequate. These contain calcium, phosphorus, potassium, chlorides, magnesium, iron, manganese, zinc, copper, iodine, cobalt and fluorine. Since most waters contain ionizable calcium which is available to fish directly through gill transfer, the proportion of calcium to phosphorus in fish foods has been estimated at 1:1, rather than the 2:1 ratio for foods of terrestrial animals. Phosphorus in phytin has the same limited availability for fish as for other animals.

Recently, Arai, Nose and Hashimoto (1971) and Arai, Nose and Kawatau (1974) have found that eels (*Anguilla japonica*) require about twice the mineral level as salmonids; up to 8% in a diet of purified ingredients. The effective level of a standard mineral mixture used for most aquarium test fish feeds is 4%. Mineral additions to a formula for feeds

TABLE II
CONTRIBUTION OF ENERGY SOURCES TO FISH FOODS

Nutrient	*Per kg fish gain*		*Per kg food*		*Per kg fish/day*	
	g	*kcal*	*g*	*kcal*	*g*	*kcal*
Protein	457	1 828	329	1 316	11 4	45·6
Fat (coldwater)	139	1 251	100	900	3·5	31 5
Fat (warmwater)	83·4	750·6	60	540	2·1	18·9
Carbohydrate (coldwater)	293	1 171	210·5	842	7·3	29·4
Carbohydrate (warmwater)	418	1 671·4	300·5	1 202	10·4	41·6

to be used in salt water are somewhat less than for those used in fresh water. Most waters contribute ionized mineral compounds which are exchanged through the gills and skin with those in the fish body by simple diffusion, enzymatic action, metabolic carriers or special cellular selection.

TABLE III
NUTRIENT TARGETS FOR EFFICIENT PRODUCTION OF FISH BASED ON GROSS FOOD CONVERSION EFFICIENCY OF 20%, GROSS ENERGY CONVERSION EFFICIENCY OF 32%, GROSS PROTEIN CONVERSION EFFICIENCY OF 35%, AND VITAMIN CONVERSION EFFICIENCY OF 50%

Specific nutrient	*Per kg food*	*Per kg fish gain*	*Per kg fish/day*
Food (g)	1 000	1 390	34·8
Energy (kcal)	3 058	4 250	106·4
Protein (g)	329	457	11·4
Arginine	19·7	29	0 684
Histidine	5·9	8 2	0·205
Leucine	12 8	17·8	0·444
Isoleucine	7·2	10	0·250
Lysine	16·5	22 9	0 573
Methionine without cystine	13·2	18·4	0 459
Methionine with cystine	3·3	4·6	0·114
Phenylalanine	16·8	23·4	0·584
Threonine	7·2	10·0	0·250
Tryptophan	1 7	2·4	0·059
Valine	10·5	14·6	0·365
Cystine (spares methionine)			
Tyrosine (spares phenylalanine)			
Fat (g)			
Coldwater fish	100	139	3 4
Warmwater fish	60	83	2 1
Carbohydrate (g)			
Coldwater fish	210	293	7 3
Warmwater fish	300	418	10·4
Vitamins (mg)			
Thiamine	10	13·9	0 3475
Riboflavine	20	27·8	0·695
Pyridoxine	10	13·9	0·3475
Folic acid	5	7	0 179
Ascorbic acid	100	139	3·475
Pantothenic acid	40	55 6	1 39
Inositol	400	556	13 9
Biotin	1	1·4	0 035
Choline chloride	3 000	4 170	104·25
Niacin	150	208·5	5·26
Cobalamine	0·02	0·03	0·0007
Vitamin A (IU)[1]	2 000	2 780	69 6
Vitamin D (IU)	2 000·	2 780	69·6
Alpha tocopherol (mg)	30	42	1·04
Menadione (mg)	80	111	2 78

[1] Much higher levels are apparently needed in laboratory diets (Aoe *et al.* 1971, Rumsey and Ketola, 1975)

2.8 *Summation*

The nutrient levels shown in Table III will enable warmwater fish to meet production goals in the moving water of tanks and raceways. In ponds and tambaks where natural food is available, these nutrients may be supplied by a combination of forage and supplemental foods. This subject should be researched in more detail in the future. The quantitative and qualitative aspects of supplemental feeding are well described by Hepher (1975) and Chervinski, Hepher and Tagari (1968). They reported, for example, that with carp feeding on bottom fauna the first limiting nutrient was energy and that a marked increase in fish production resulted from using high-carbohydrate foods. As total protein became limiting due to overharvesting of forage, an increase in food protein resulted in another marked increase in fish growth.

Foods containing less nutrient density than shown in Table III could produce the desired fish growth (2·5%/day) if consumed in larger quantity, or if the protein had a higher efficiency or if variations in fish management allowed more efficient food conversion. Most coldwater fish will meet production goals more efficiently with foods of higher nutrient density than those shown in Table III, *eg*, 36–40% protein for developing trout and salmon.

3 Fish feed manufacture

The physical properties of a fish feed are as important as its nutrient content. Feeds must be prepared in such a manner as to be available, acceptable, ingested and digested. Natural foods are selected by fish for ease in capture and their adaptation to the gastrointestinal tract and are often aided in digestion by autolysis. These are objectives to be attained by any techniques of feed formulation and preparation that are economically feasible.

Several recent publications have dealt adequately with fish feed manufacture, *eg*, Gaudet (1971) and Hastings and Dickie (1972). Since these papers were published, several important fish species have been added to the list of those used in commercial aquaculture and new data are available on formulation and feed processing.

3.1 *Meals, pastes and cakes*

Feeds for plankton-feeders, algae-grazers, fry, larvae and small fingerlings may be prepared as dry meals, colloidal suspensions, or soft cakes. They are consumed by direct capture or by filtering water at random. Unless the water in an impoundment is in motion and meal feeds remain in suspension, many particles settle to the bottom and are uneaten. To prevent sorting and selection of ingredients and to increase consumption, meal mixtures may be sifted for uniformity and then: (*i*) sprayed with oil, condensed fish solubles or homogenized fish tissue—to reflect light, repel water and cause dust-like particles to adhere to larger particles: (*ii*) mixed with water and formed into a paste or cake with the binding action of proteinaceous or starch-gelling compounds, such as cassava, soycake, sago root, sticky rice, alginates, gelatin and synthetic gels (carboxy methyl-cellulose). These may be forced under water through holes in a screen to become colloidal suspensions similar in appearance and size to diatoms and individual *Chlorella*, or the mixture may be formed into ribbons by a grinder or syringe or into lumps or cakes by hand.

A 'home industry' type of feed manufacture may be used for eels, milkfish and shrimps. Cooked (pregelatinized) potato starch at 20–25% dry weight basis, plus 25–30% water, forms a paste with fish meal, soybean meal and rice bran as a food for eels (Nose and Soma, 1970). Dried cassava at 15% or extracted tapioca at 5% with 40% water, or fresh cassava at 40% of the formula, fortified with shrimp heads, fresh fish or fish meal, coconut meal and rice bran, may be formed into small cakes and steamed to become a soft yet water-stable feed easily grazed by milkfish and shrimps (Hastings, 1975).

Feed prepared as above may be dried, ground and sifted to desired particle size for meal-type diets. Ingredients clumped together in this manner, by mixing, wetting and drying, are quite water stable, have little nutrient loss on processing and often retain the lure of natural foods.

3.2 *Pelleted feeds*

For convenience in storing, transporting and dispensing in automatic feeders and self-feeders, many fish feeds are prepared in pellet form. A wide variety of machinery is

available to compress, expand, roll, or otherwise shape feed mixtures into bite-size units containing 10–40% water.

The bulk of fish feeds purchased by US Federal and State fish hatcheries specify the use of 'open formulae' and their processing into dry pellets and granules. At slightly more cost, the same feed can be purchased in expanded or floating form. At still higher cost, a semi-moist food using some wet fresh or frozen ingredients may be purchased. Most cultivated fish can be trained to accept a dry sinking pellet, an expanded floating pellet or a soft wet pellet. Differences in management procedures plus idiosyncracies of the fish species and their age, size, and previous history, determine which feed to use.

3.2.1 *Hard pellets.* The general process for hard pellet manufacture involves passing a mixture of soft meal-type food through a high-speed paddle mixer where 4–6% water is added as steam. Moisture provides lubrication for compression and extrusion and, in the presence of heat, causes some surface gelatinization of raw starch present in vegetable ingredients. Within 20 seconds of steam conditioning, the food changes from air-dry moisture (about 10–12%) and ambient temperature to 15–16% moisture and 80°–85°C. During subsequent compression and extrusion in a ring die, friction further increases food temperature to nearly 90°C. Pellets discharged onto a screen belt or a horizontal drier or into a vertical screened hopper are air-cooled within 10 minutes to slightly above ambient temperature and dried to below 13% moisture. Gelatinized starch has a binding and water stabilizing effect on all ingredients.

Compression and extrusion through holes in a ring die change the texture of a food mixture from a free-flowing meal with bulk density of approximately 0·45 g/ml, to pellets with bulk density approximately 0·7 g/ml. These may be used either as pellets or roll-ground into granules and sifted to an intermediate size and bulk density. This process provides the fish with a concentration of nutrients seldom available in natural foods.

Since the greatest volume of proprietary formula feeds used for domestic terrestrial animals is prepared as hard pellets, it has been assumed that this method of manufacture should also be used for commercial fish feeds. Hard pellets and granules may be used for fish with a mouth-size capable of ingesting them, the stomach capacity to store them and the peristaltic action and enzymatic ability to digest them. Even if not ingested as single units of feed, some fish pellets have proved to be more economical than meal-type foods. Minnows (*Pimephales promelas*) and channel catfish fingerlings over 2·5 cm in length (Prather, 1958) have a better growth and food conversion and their environment is less polluted by uneaten foods when they consume pellets which disintegrate in water rather than when fed the same quantity of food as a meal.

For some fish, there is a danger of overfeeding with hard pellets which may cause swelling and rupture of the stomach. Overfeeding may also mechanically force pellets past the point of gastric activity resulting in inefficient digestion (Windell, pers. comm.). Another hazard with hard pellets may occur during winter feeding when fish ingest food to their full stomach capacity on a warm day which is followed by a period of cold weather. This may result in fermentation of undigested food in the stomach, causing the fish to float upside down and exposing them to extremes in air temperature and predation.

Feed formulae containing large quantities of fibrous ingredients (alfalfa meal, dried *Anacharis*, mill screenings, *etc*) cause pressures within the pellet die ring often exceeding 500 kg/cm^2 which result in pellets too hard for normal gastric breakdown and digestion. However, the usual commercial fish feed pellet manufactured for sensory feeders provides a balance between hardness, water stability and rapid digestion. The author has analysed the gastrointestinal tracts of channel catfish 15 minutes after feeding them hard pellets and found 10% of the total body weight to be stomach contents. In that time, sufficient moisture had been ingested or absorbed from body tissues to soften the pellets into a mush containing 70% water.

Some fish (carps for example) are slow feeders, often taking an hour to locate and ingest a day's food allotment. During this time the standard feed pellet disintegrates into individual components and is not efficiently recovered. Pelleted feeds may achieve extra water stability without excessive hardness by using 25% whole wheat instead of wheat by-products as a cereal component, or by increasing raw starch gelatinization by heat drying (Hastings, Meyers and Butler, 1971). The time required for fish to locate food may be greatly decreased by the use of self-feeders which alert fish to small amounts dispensed with each 'strike' and increase feeding activity by competition.

Feeds manufactured by hard pelleting machinery are acceptable to a wide variety of fishes, *eg*, trout, salmon, catfishes, eels, tilapias, carps, and grey mullets (*Mugil* spp.). Differences in formulation have required special designs of ring dies used in compression and extrusion. A high-fat (up to 12%) feed can be successfully formed in a thick-rimmed die using fibrous ingredients to provide compaction or by adding pre-gelatinized starch to aid in binding. High-fat pellets may also be prepared using low-fat formulae and spraying extra fat onto the food as it travels through a cooling reel.

Contrary to early belief, foods processed into hard pellets contain practically all the nutrient values found in the soft meals as compounded. Diastatic enzymes inherent in the soft meals are not impaired by steam conditioning. The slight loss of some thermolabile vitamins used in additives may be compensated for by using extra amounts of these in the vitamin premix and complying with requirements in the diet.

The cost of manufacturing pellets is about 3–4% more than for the same formulae in soft meal form, and even with careful handling, pellets break down into some amount of 'fines' which are unacceptable or unavailable to fish. In general, however, savings in storage space, bulk handling, and mechanical dispensing more than pay for the extra cost of pellet manufacture and loss of fines.

3.2.2 *Soft pellets.* Certain fish which strike for their food prefer soft, leathery, pliable pellets. This texture can be attained by using a high-compression hard pellet mill and adding fat, lecithin or water up to a total of 18–20% moisture. Normally, the moisture of feeds stored at ambient temperature must be below 13% to prevent microbiological growth. Pellets with moisture content higher than 13% must be used within a short time after production and stored at cool temperatures, or include a fungicide in the formula.

Groves (1974) suggests another process of improving acceptance of hard pellets by small Pacific salmon

(*Oncorhynchus*). Pellets are placed in a container with a perforated bottom, dipped briefly into water and drained for 20 minutes. The pellets still retain the texture of a compressed feed and the softened surface attracts sight feeders which strike for food as soon as it is placed in water.

The greatest volume of soft, moist feed is made by the 'Oregon moist pellet' process. The diet is formulated with about 30–40% wet fresh or frozen fish (whole, viscera, raw or cooked) added to a dry meal of variable constituents and mixed until sticky and doughy in texture. The mix is then forced through holes in a plate similar to that used in the manufacture of macaroni, cut off in appropriate lengths and stored frozen. When thawed, this food is readily accepted by small Pacific salmon and bass (*Micropterus*) which reject hard pellets.

4 Conclusions

The overall objective of studying fish nutrition and fish feed manufacture is to increase the production of fish used as human food and for recreation. The manufacture of fish feeds, especially in developing countries, may often be facilitated by compounding local food ingredients and using local processing facilities.

With proper formulation and processing, the efficiency targets presented in this paper are attainable in any part of the world.

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The Nutritional Requirements of Cultivated Warmwater and Coldwater Fish Species[1]

J. E. Halver

Abstract

A formula for balanced fish diets must include an energy source plus sufficient indispensable amino acids, essential fatty acids, specific vitamins and minerals to support life and to promote adequate growth. Tentative requirements for the ten indispensable amino acids and sparing effect of several others are reported for only a few species of fish held under specific experimental conditions. These must be confirmed for other species reared and conditions used, since the protein requirement and amino acid balance is the major determinant for growth, and is the greatest food source problem.

Essential fatty acid needs for fish reared indicate that this component may be the second limiting factor for future practical diets. Water-soluble and fat-soluble vitamin needs have been reported for only a few fish and must be extended to those reared in different waters. Digestibility coefficients of diet ingredients, measured for terrestrial animals, need confirmation in fish to translate nutrient ingredient source data into computer diet formulae.

Specific nutrient requirements vary with species, size, temperature,

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stress, and nutrient balance; thus, economical rations must be programmed accordingly. Techniques have been developed for Metabolizable Energy and diet component digestibility for several species and can be expanded to generate hard data for scientific fish husbandry diets and rations.

Les besoins nutritionnels des poissons élevés en eaux chaudes et en eaux froides

Résumé

Une formule de régime alimentaire equilibré pour les poissons doit inclure une source d'énergie ainsi que les acides aminés indispensables en quantité suffisante, les acides gras essentiels, les vitamines et les minéraux spécifiques, pour pouvoir entretenir la vie et promouvoir une croissance adéquate. On n'a signalé à titre indicatif les dix acides aminés indispensables et les effets d'épargne de plusieurs autres que pour quelques especes de poissons maintenus dans des conditions expérimentales spécifiques. Ces resultats doivent être confirmés pour d'autres espèces et pour d'autres conditions d'élevage, étant donné que les besoins protéiques et l'équilibre des acides aminés sont l'élement déterminant de la croissance et constituent le problème majeur quant au choix des aliments.

Les besoins en acides gras essentiels des poissons eleves indiquent que ce composant pourrait constituer le second facteur limitant des regimes alimentaires formulés à l'avenir dans un but pratique. On n'a signale les besoins en vitamines solubles dans l'eau et dans les graisses que pour quelques poissons; il faut joindre a ces donnees des indications relatives aux espèces élevées dans des eaux différentes Les coefficients de digestibilite des substances entrant dans le régime alimentaire, mesures pour les animaux terrestres, ont besoin de confirmation dans le cas du poisson pour que l'on puisse convertir les donnees relatives aux substances nutritives en formules de regime alimentaire etablies sur ordinateur.

Les besoins en nutriments specifiques varient en fonction de l'espèce, de la taille, de la température, du stress, et de l'équilibre des nutriments. Les rations économiques seront ainsi programmées en consequence. L'on a mis au point des techniques afin de déterminer l'energie métabolisable et la digestibilité des composantes du régime alimentaire pour plusieurs espèces, et l'on peut les developper en vue de produire des données en clair permettant d'etablir sur une base scientifique des regimes alimentaires et des rations destinees à l'elevage des poissons.

Necesidades nutricionales de las especies de peces cultivadas en aguas frías y cálidos

Extracto

Los preparados destinados a ofrecer a los peces una racion alimenticia equilibrada deben incluir, ademas de una sustancia energetica, los aminoácidos indispensables, en cantidad suficiente, los acidos grasos esenciales, determinadas vitaminas y algunos minerales Sólo así sera posible que los peces se mantengan vivos y crezcan en forma adecuada. Se indican con caracter provisional, para algunas especies de peces criadas en condiciones experimentales especificas, las necesidades de los 10 aminoácidos indispensables y el efecto economizador de otros varios. Es necesario confirmar esas necesidades para otras especies y otras condiciones de cría, ya que las necesidades de proteinas y el equilibrio de aminoacidos son los principales elementos que influyen en el crecimiento y representan el principal problema a la hora de optar por alimentos de diversos orígenes.

Las necesidades de los peces cultivados por lo que se refiere a acidos grasos esenciales indican que tal vez sea este elemento el segundo factor que ha de tenerse en cuenta al preparar raciones alimenticias practicas para el futuro. Los datos sobre necesidades de vitaminas hidrosolubles y liposolubles no se refieren más que a algunas especies de peces, y es necesario extenderlos a especies cultivadas en aguas diversas. El coeficiente de digestibilidad de los ingredientes de la ración alimenticia medido en animales terrestres ha de confirmarse en los peces para poder preparar, sobre la base de los datos conseguidos sobre los diversos nutrientes, fórmulas elaboradas en programas de computadoras de preparados alimenticios especificos

Las necesidades concretas de nutrientes varian segun la especie, la talla, la temperatura, la tensión ambiental y el equilibrio de los diversos nutrientes en la racion alimenticia; es necesario, pues, programar las raciones teniendo eso en cuenta, para que sean economicas. Se han preparado algunas técnicas para determinar, en varias especies de peces, la Energía Metabolizable y la digestibilidad de los elementos de la ración alimenticia. Esas técnicas podrán extenderse a otras especies para obtener datos seguros en orden a la preparación de raciones alimenticias científicas para piscicultura.

1 Introduction

Any balanced formula for fish diets must include an energy source plus sufficient indispensable amino acids, essential fatty acids, specific vitamins, and minerals to support life and to promote growth. Over the past 20 years, tentative requirements have been determined for the five classes of nutrients in the diet of rainbow trout (*Salmo gairdneri*) (NAS/NRC, 1973). The requirements have been found to change with fish size, with water temperature, and with the balance of components in the ration (Halver, 1972). These data have been translated into practical fish diets through least cost computation using fish feed ingredient nutrient analysis. As dividends from this research and development effort, practical rations for rainbow trout can now be formulated throughout the world from locally available dietary ingredients and can be used with a reasonable degree of assurance to rear rainbow trout to either market size or to broodstock. The same story is not so clearly defined for other species of fish and it is appropriate to review what is known about specific nutrient requirements for other salmonids, ictalurids, cyprinids, and several other fishes of potential economic importance.

2 Amino acid requirements

All fish species used in experiments so far examined require the same ten indispensable amino acids for growth (Cowey and Sargent, 1972; Mertz, 1972). Arginine, histidine, isoleucine, leucine, lysine, methionine, phenylalanine, threonine, tryptophan, and valine must be in the diet, and must be present in near balanced amounts to furnish an acceptable amino acid pattern before fish flesh can be formed. These indispensable amino acids in proper proportion are determinants for success or failure of any fish husbandry programme.

Many practical rations used in salmonid fish production programmes in the United States have been assayed for amino acid content (NAS/NRC, 1973; Wood *et al*, 1957; Halver, 1957 and 1972a). These values compare closely with the amino acids present in fish egg protein and with chicken egg protein (Halver, 1957). Therefore, most of the amino acid test diet work and subsequent quantitative amino acid requirements have used the amino acid pattern of whole egg protein as a standard reference protein for these studies. Fish that are fed diets devoid of any indispensable amino acid fail to grow, whereas other fish that are fed diets devoid of dispensable amino acids grow as well as control diet fed fish receiving all amino acids in the reference protein (Halver, 1957). Arginine was determined to be an indispensable amino acid for salmonids (Halver, DeLong and Mertz, 1957; Halver and Shanks, 1960; Shanks, Gahimer and Halver, 1962), for ictalurids (Dupree and Halver, 1970), and for cyprinids (Aoe *et al*, 1970). Lysine, the first probable limiting amino acid in cereal grain or oil seed protein components, also determined the rate of growth of fish. A direct response was also obtained with methionine content in fish diet with growth rate determined directly by percentage of methionine present. Likewise, tryptophan was required; scoliosis and lordosis appeared when low levels of this amino acid were present in the ration (Halver, DeLong and Mertz, 1957; Halver and Shanks, 1960; Shanks, Gahimer and Halver, 1962; Dupree and Halver, 1970).

A new simple technique has shown that all fish tested required the same ten indispensable amino acids (Cowey, Adron and Blair, 1970). Fish were given intraperitoneal injections of 14-carbon uniformly labelled glucose. After radioactivity in the expired carbon dioxide had been measured for several days, the fish were sacrificed, the tissue protein was isolated and hydrolyzed, then the constituent

amino acids were resolved and purified. These amino acids were examined by paper chromatography for radioactivity. Those amino acids which contained radioactive material were obviously synthesized by the fish from other metabolites and were not essential dietary constituents. Conversely, those amino acids which did not contain radioactivity could not have been synthesized by the fish. These were classified as indispensable and necessary to be present in the diet. Marine flatfish examined with this technique were found to require the same ten indispensable amino acids as freshwater fish (Cowey, Adron and Blair, 1970).

Quantitative amino acid requirements have been determined using protein reference diets or by analysis of dietary ingredients in fish feed ingredient mixtures (DeLong, Halver and Mertz, 1958). Protein test diet formulations have been used successfully in several species. Protein treatments showed that the apparent protein requirement was about 50% of the dry diet ingredients for fry, with a reduction in requirement as fish increased in size (NAS/NRC, 1973). Trout and salmon had the same apparent protein requirement when the animals were raised at the same temperature.

Some experiments have shown that the protein requirement increased in salmonids as the salinity increased and that the rainbow trout requirement of 40% of the diet as protein at 10‰ salinity, increased to 45% of protein in waters of 20‰ salinity (Zeitoun *et al*, 1973). The same phenomenon was observed with coho salmon (*Oncorhynchus kisutch*) on feeding trials that measured brackishwater saline content (Zeitoun *et al*, 1974). Carp (*Cyprinus carpio*), eel (*Anguilla japonica*), and channel catfish (*Ictalurus punctatus*) also showed a high protein requirement for very young fish which decreased with age to only about 25% of the diet in yearling catfish held in 25°C of water. Several sea fish appear to require more than half the diet ingredients as protein components and are thus more carnivorous than other carnivores listed (Yone, Sakamoto and Furuichi, 1974).

The protein requirement of the fish has a direct bearing upon the indispensable amino acid pattern of formulated test and practical rations. Quantitative indispensable amino acid requirement studies have been conducted on salmonids, on catfish, on eel, and on red seabream (*Sparus major*). Test diets have been prepared which enable linear increments of one amino acid at a time to be fed at different diet treatments in feeds containing some whole protein components to stimulate the digestive and absorptive processes. Almquist-type plots of the growth response to these different diet treatments produced typical inflection points for each of the ten different indispensable amino acids when the test diets contained:

Amino acid	*Percentage in diets*
Arginine	2·5
Histidine	0·7
Isoleucine	1·0
Leucine	1·5
Lysine	2·1
Methionine	0·5
Phenylalanine	2·0
Threonine	0·8
Tryptophan	0·2
Valine	1·5

Subsequent experiments have shown a sparing action of cystine on the methionine requirement, and of tyrosine on the phenylalanine requirement. The combined methionine and cystine requirement appears to be about 1·5% of the dry ration with the best growth observed when 1% of cystine and 0·5% of methionine was fed to salmonids. Approximately one third of the phenylalanine growth requirement could be spared by L-tyrosine in some experiments (Halver, 1970a).

Toxic effects of gross imbalance of some of the indispensable amino acids were also observed. An inhibition of growth and diet performance was observed when either isoleucine was threefold in excess of leucine, or when threefold leucine was fed with the isoleucine held at the requirement. High intake of valine also inhibited growth in salmonids (Chance, Mertz and Halver, 1964).

DL-mixtures of amino acids have been tested and little growth was obtained in salmonids when three or more DL forms of indispensable amino acids were incorporated in the diet. D-amino acid oxidase has been isolated and measured in young salmon and trout and in actively feeding sea salmon in the ocean environment. Much variation was obtained in D-amino acid oxidase activity between fish and between the seasons of the year in which samples were obtained and processed, indicating it would be unreliable to expect salmonids to process excessive amounts of D-amino acids in the dietary protein. Toxic effects from these enantiomorphic forms of amino acids can be expected (Halver, 1970a).

Nitrogen sources for fish have been examined and little sparing effect on the whole egg protein requirement was obtained with urea or diammonium citrate (DeLong, Halver and Mertz, 1959). Arginine could be effectively used to spare dispensable amino acid protein, but glycine had only a minor sparing effect on protein requirement in salmonids. Thus, fish react differently from other experimental animals in their ability to utilize simple nitrogen sources as intermediates for dispensable amino acid synthesis. Amino acid test diets, when the protein component is made of L-amino acids, did not work well in young carp (Aoe *et al*, 1970), in catfish (Dupree and Halver, 1970), or in red seabream (Yone, Sakamoto and Furuichi, 1974). Little or no growth resulted when these diets were fed either as amino acid mixtures or as hydrolosates of casein, gelatin, or other proteins and the hydrolosate was then incorporated in the ration as the major protein component. Digestive and absorption physiology is apparently different in these fishes and the indispensable amino acid requirements must be determined by using whole protein mixtures to arrange and adjust the diet treatments for indispensable amino acid levels. An appetite-stimulating effect has been reported in seabream upon the addition of alanine, tyrosine, or serine to the test diet (Yone, Sakamoto and Furuichi, 1974). Thus, fish can be expected to react differently between species on specific amino acid patterns in the protein component of the ration.

Amino acid test diet trials with eel showed that 1% of cystine and 1% of methionine increased the growth response and diet efficiency (Hashimoto, 1975). The apparent requirement for histidine was higher than in salmonids and the methionine requirement was determined to be over 3% of the protein component. This value is about twice as much as that estimated for salmon fed diets containing 1% of cystine in the ration. The tryptophan requirement of

the eel is also about twice as much as that of salmonids. These differences between species can be expected to occur in quantitative indispensable amino acid requirements. Likewise, the sparing effect of a particular dispensable amino acid upon the requirement for some indispensable form will often vary between species tested. These observations emphasize the need for confirmatory feeding trials using appropriate test diets plus careful amino acid analysis of protein components in test rations to define the specific amino acid requirements for each fish raised in each specific environment.

A practical method to estimate indispensable amino acid requirements of fish is to examine the proportion of each present in the protein component of the ration. An example might be the amino acid requirements of salmonids when 40% of the diet is protein fed to young rapidly growing fish at 10°C. A remarkable and consistent percentage of the protein for each is obtained when the gramme percent quantities of the individual amino acids are compared between rainbow trout, chinook salmon (*Oncorhynchus tshawytscha*) and coho salmon (Mertz, 1969).

Slight differences are observed only between histidine and isoleucine requirements, and phenylalanine, threonine, and valine requirements. Only lysine shows a major difference between species when the gramme percentage quantities are extended into percentage of dietary protein. The gramme percentage of the indispensable amino acid required may drop as the fish grow larger, but so does the protein requirement. Thus, the percent of the amino acids in the dietary protein is a reasonable measurement of amino acid requirement (Mertz, 1969).

3 Utilization of dietary protein

Sufficient energy must be present in the diet to convert these ingested amino acids into tissue and the calories per gramme protein ratio will affect Protein Efficiency Ratio and Net Protein Utilization. Salmonids can use some digestible carbohydrate as an energy source, but cooked or processed starch in common fish diet ingredients must be used before many digestible energy calories can be obtained from these materials (Buhler and Halver, 1961). Therefore, not only the type of diet ingredients but the method and degree of processing will determine the availability of the energy in this component to salmonids and several other fishes studied. Monosaccharides are best used, followed in order by disaccharides, simple polysaccharides, dextrins, cooked starches, and raw starches. Some fish harbour gut bacteria which contain cellulases which can hydrolyse and make available some monosaccharides from cellulose. The role of fat to furnish the energy source will be discussed later.

Most amino acid quantitative studies have been conducted with very digestible protein components to furnish the amino acids or with amino acid mixtures which will guarantee rapid absorption of the test nutrient fed. This technique is logical to catalogue the indispensable amino acid requirements and to measure the sparing effect of certain dispensable amino acids on these requirements for various species of fish to be reared in defined experimental conditions. Much more work needs to be done with important commercial types of fish confined in our fish husbandry production facilities because information on the indispensable amino acid requirements, and a good pattern for fish rations, will allow least-cost computer formulation of practical rations and improve the efficiency and economics of the industry. However, when testing amino acid patterns in practical rations one must first calculate that portion of the protein component that is digested and absorbed. Only if the amino acids are absorbed and contribute to tissue synthesis can protein be deposited for fish tissue repair and for growth.

Chemical score—the ratio of indispensable amino acids present in the finished feed component to the indispensable amino acids present in whole egg protein—is only a partial measure of what the fish actually get from the protein fed (Hastings, 1969). These amino acids which would be limiting as far as the requirement of the animal is concerned for that particular ration can be calculated, but a more finite prediction can be obtained when the digestibility coefficient of the protein component is measured by pepsin or papain digestion, by formal titration, or by pancreatic digestion techniques. Then a better approximation of biological value of the protein component can be obtained.

A much better approximation of biological value of the protein component can be obtained from metabolism chamber experiments where the actual percent of protein or specific nutrients fed is measured and compared with the metabolic wastes which are collected and analysed for nitrogen or for other nutrient components (Smith, 1971). Large fish have been used in these metabolism chambers to measure what proportion of feed fed is actually digested, absorbed, and metabolized by the fish. The assays give a tentative digestibility coefficient for that particular species of fish for the components in that diet ingredient tested, either alone or in combination with other diet components for which Gross Energy, Digestible Energy, Metabolizable Energy and digestibility coefficients of the nitrogen and energy components have been established. More recently, techniques have been developed in closed aquarium systems for very small fish which will adapt to the closed confinement. The results have been compared with large fish tested in metabolism chambers. Oxygen utilization, carbon dioxide generated, and soluble nitrogen wastes in fish feed give an estimate of the energy needs of the fish under various stages of resting or active metabolism. These values vary with the temperature, with the species, with the size, and with the stress invoked.

A combination of these techniques can be used to determine the Nutritional Score of the ingredients in the ration. Arginine will be found limiting in many of the components since most fish tested require about 6% of the protein to be arginine for the most efficient growth. Also, arginine can be used as a nitrogen supplement to spare other whole protein requirements in the diet of salmonids or ictalurids, and therefore deserves special mention and consideration. Methionine, and methionine plus cystine, will be found limiting in single-cell protein diet ingredients and in larval protein components of fish diets. Lysine is the first limiting amino acid in many cereal and grass components. Tryptophan, because of its higher requirement, will become limiting in many rations especially for eel diets. It deserves careful scrutiny since it is easily destroyed under acidic conditions of diet ingredient storage such as in fish silage or in moist pellet manufacturing processes. The great reactivity of the epsilon amino group of lysine with aldehydes in sugars forming Maillard-type compounds may mislead the investigator if diet formulations are based solely upon

analysis of diet ingredients or finished feeds for indispensable amino acid content. Obviously, biological availability of these reactive amino acids is necessary and simple amino acid analyser values do not reflect either the optically active form of the amino acid or the biological availability of it to the fish fed. However, with these constraints in mind, one can make tentative predictions for the indispensable amino acid requirement and an approximate pattern for fish to produce reasonable growth.

A first approximation for an acceptable amino acid pattern would be the indispensable amino acid requirements present in the digestible protein component absorbed by that species of fish at the size, age, stress, and temperature measured plus the balance of the protein component made up of dispensable amino acids in the pattern found in whole egg protein. A usable approximation is the individual percent of protein occupied by indispensable amino acids present in the digestible protein fraction of the ration, and the dispensable amino acids constrained not to exceed two times the level found in whole egg protein or fish flesh. These values can be used for least-cost computer formulation of the ration, provided the digestibility coefficient for the nitrogen component is added as a function of the calculations.

4 Fat requirements

Fats are a ready source of energy for fish and most studies indicate fish can use 20–30% of the dry diet ingredients as fat, provided adequate amounts of choline, methionine, and tocopherol are present in the ration (Lee and Sinnhuber, 1972). Fats have the distinct advantage of being almost completely digestible. Fish appear to be designed to metabolize fats efficiently as an energy source, with concomitant sparing effect on the protein requirement to produce maximum growth. The neutral lipid component of the fish ration is therefore a useful component for diet formulation and is especially desirable in fry or fingerling feeds when higher energy intake is necessary to promote rapid growth. This asset is not without serious constraints, however, because some fish, such as rainbow trout, plaice (*Pleuronectes platessa*), and red seabream (*Sparus major*) do not have the specific ability to elongate short-chain fatty acids, and then unsaturate the carbon chain to convert simple animal or vegetable fats into polyunsaturated long-chain fatty acids characteristic of fish tissue lipids (Yone, Furuichi and Sakamoto, 1970).

Essential fatty acid requirements have been demonstrated for several species of fish, and while linolenic acid appears to satisfy some of the growth requirement, more polyunsaturated and longer-chain fatty acids of the C_{22} or C_{24} omega-3 series are required for maximum growth and efficient diet utilization (Lee and Sinnhuber, 1972). These polyunsaturated fatty acids have concomitant requirements for adequate amounts of tocopherols to prevent fatty acid peroxidation, chain rupture, and subsequent toxic reactions in the liver and spleen. Fats do form an important part of practical fish rations for energy and, in addition, must supply the essential fatty acid requirements for that particular species of fish raised.

5 Vitamin requirements

Vitamin deficiency diseases have been described for many species of fish (Halver, 1972). Test diets are available which can induce specific water soluble or fat soluble vitamin deficiency symptoms in salmonids, ictalurids, cyprinids, eel, and several marine fishes. The water soluble vitamins function in fish metabolism as in homeothermal metabolism. The primary difference is one of reaction rates of the enzymes involved in poikilothermic animals reared in variable water temperatures. The water soluble vitamins are part of co-enzyme systems in the same fundamental biochemical pathways as in other animals. Thus, deficiencies induce specific metabolic system failures with resultant deficiency signs. These have been described and compared with other experimental animals by several groups of workers (Halver, 1972). Tentative requirements in terms of milligrammes of vitamins per kilogramme of body weight per day have been listed as: thiamin, 0·13–2·0; riboflavin, 0·75–1·0; pyridoxine, 0·38–0·43; choline, 50–70; niacin, 5–7; pantothenic acid, 1·3–2·0; inositol, 18–20; biotin, 0·03–0·04; folic acid, 0·1–0·15; vitamin B_{12}, 0·0002–0·0003; and ascorbic acid, 2–3 (*eg*, NAS/NRC, 1973). Sparing effect of one vitamin or vitamin precursor on others has not been thoroughly investigated and specific differences in requirements of animals on different carbohydrate or fat intake and different protein intake have not been adequately measured. Since the requirement for thiamin is related to the carbohydrate intake in most other animals studied, this vitamin may become more important for certain carbohydrate-consuming species of fish, such as the grass-eating fishes, the mullets (*Mugil*) and many others which eat phytoplankton or are herbivorous. Likewise, requirements for pyridoxine are related to the protein level in the ration and as a consequence pyridoxine is one of the first vitamins exhausted in carnivorous fish fed low pyridoxine diets. The requirement for ascorbic acid may vary with the rate of protein synthesis or with the stress under which the fish is held. For example, the ascorbic acid intake to promote most rapid growth for long-term salmon and trout experiments at 15°C needed to be increased three- to five-fold to promote the most rapid rate of wound repair when the fish were stressed with a 1 cm incision through the skin into the abdominal cavity or above the lateral line into the musculature (Halver, 1972a). More work needs to be done in this area to determine specific requirements of these water-soluble vitamins for different dietary treatment for different fishes, sizes, water temperatures, and stresses experienced.

The fat-soluble vitamin requirements have been less discretely defined than in the studies with the water-soluble vitamins. Tissue storage of the fat-soluble vitamins is accumulative and hypervitaminosis can also be expected to be encountered when high intake of diet ingredients containing large amounts of fat-soluble vitamins are fed for long periods to fish. Qualitative fat soluble vitamin experiments have disclosed that vitamins A, K, and E are required for normal growth and maturity of salmonids. Typical deficiency symptoms occurred when these components were absent from the diet. Vitamin D has not been shown to be required for normal growth and function of salmonids in high calcium water, but recent work has disclosed that vitamin D_3 exercises a beneficial effect to promote absorption of calcium from the gut in certain water systems and exercises a growth-promoting effect in several test situations (Poston, 1968). Hypervitaminosis D has also been reported to occur in salmon fed diets containing large

amounts of fish liver oil. It occurs as acute liver toxicity, growth inhibition, poor food conversion, and elevated alkaline phosphate activity in the blood. Therefore, fish, like other experimental animals, have specific quantitative requirements for the fat-soluble vitamins and these requirements can be altered by the particular species of fish, the size, the water temperature, and the environmental and dietary conditions under which the animals are reared.

6 Mineral requirements

Little is known about the trace-mineral requirements of fish for these enzyme activators. Macro-mineral requirements have been studied with a few species under carefully controlled experimental conditions (NAS/NRC, 1973). Calcium is known to be sequestered from the water through the gill tissues in trout. Likewise calcium can be absorbed through the gut when adequate amounts of vitamin D_3 are present in the ration. Several calcium:phosphate balance ratio studies have indicated that most practical fish diets contain adequate amounts of calcium but phosphate is often inadequate. Also, the particular form of phosphate must be analysed in diet ingredients because of the unavailability of phytic salts which are commonly present in agricultural products. Therefore, the type of phosphate and its availability to the fish should be measured and gross chemical analysis should not be relied upon for computer data bank input for specific diet ingredients. A sodium:potassium balance is especially important in fish in a marine environment or in fish moving from one ionic strength environment to another, such as in anadromous migrating smolts. Sodium-potassium activated gill ATPase activity offers a convenient tool for determining the ability of the young smolt to activate the sodium pump and thus convert to an oceanic environment. Dietary pretreatment with high sodium diets stimulates the early elevated activity of this compound when the fish have been environmentally conditioned to smolt, and then migrate to the sea.

One of the first recorded specific trace-mineral deficiency symptoms in rainbow and brook (*Salvelinus fontinalis*) trout was described 50 years ago when fish were reared on diets deficient in iodine (Gaylord and Marsh, 1914). Acute proliferation of thyroid tissue, a compensatory reaction, occurred and fish developed typical goitre. Advanced cases would actually invade surrounding tissue which was at first mistaken for neoplasia. Intermediate stage thyroid proliferation could be reduced with adequate intake of iodide, however. Recent work with cobalt has indicated that it is not incorporated into vitamin B_{12} in fish tissues and that the total amount of cobalt present in fish, especially in a fish embryo, is present in the form of organically bound vitamin B_{12}. The role of dietary cobalt to stimulate the production of vitamin B_{12} by gut bacteria has not been clearly defined and, as a consequence, small amounts of cobalt are still used as a supplement in practical fish diets. Probably the other classical trace-mineral elements are also required to activate several enzyme systems in actively growing fish; consequently, they are included in the trace-mineral supplement in diet formulations.

7 Conclusions

It can be concluded that tentative requirements have been determined for one or two fish species for: water-soluble vitamins; fat-soluble vitamins; the ten indispensable amino acids; gross protein needs; and some essential fatty acids. These values, plus a 50–100% safety factor have been incorporated into diet ingredients for least-cost computer formulation of practical fish diets. Much more work needs to be done to define specific requirements for other fish species which are being fed these rations and for determining specific requirements of such diet cost determinants as protein and amino acid needs for particular fish and particular environment at particular temperature. Tools have been fashioned, techniques have been developed, and principles have been confirmed for systematic and orderly nutritional research with fish which will yield: (*i*) specific nutrient requirement values; (*ii*) the digestibility coefficients; and (*iii*) the sparing effect of one nutrient upon another as practical, effective, efficient fish rations are formulated from the diet ingredients available from agricultural and aquacultural industries. As more information becomes available, it will be fed into the computer data bank to formulate more precise, specific diets which can be used with a greater degree of reliability in producing fish through scientific fish husbandry.

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Studies on the Nutrient Requirements of Rainbow Trout, *Salmo gairdneri*, Grown in Sea Water and Fresh Water

S. P. Lall and F. J. Bishop

Abstract

Experiments were conducted to determine the basic differences in protein, lipid and mineral utilization by rainbow trout grown in sea water and fresh water. Some significant differences were found in protein and lipid utilization. Approximately 50% protein was required in the diet for maximum growth, feed efficiency and survival in sea water. A lack of $\omega 3$-type fatty acids in the diet caused high mortality of fish reared in sea water, but did not cause mortality in fish reared in fresh water. The levels of essential amino acids in plasma were not greatly affected by the salinity. However, the levels of taurine, β-alanine, aspartic acid, glutamic acid and glycine were significantly lower in saltwater fish compared with freshwater fish It appears that fish can derive sodium, potassium and magnesium from the sea water, but calcium and phosphorus deposition in the body is reduced by the presence of these minerals in the diet.

Etudes sur les besoins en éléments nutritifs de la truite arc-en-ciel, *Salmo gairdneri*, élevée en eau de mer et en eau douce

Résumé

Des expériences ont été réalisées pour déterminer les différences fondamentales de l'assimilation des protéines, des lipides et des sels minéraux chez les truites arc-en-ciel élevées en eau de mer et en eau douce On a trouvé des différences sensibles quant à l'assimilation des protéines et des lipides. La nourriture devait contenir environ 50% de protéines pour que la croissance, l'efficacité alimentaire et la survie en eau de mer atteignent leur valeur maximale L'absence d'acides gras du type $\omega 3$ dans la nourriture a provoqué un taux de mortalité important chez les poissons élevés en eau de mer, mais non chez les poissons élevés en eau douce Le niveau des amino-acides essentiels dans le plasma n'a pas été grandement affecté par la salinité. Cependant, la teneur en taurine, β-alanine, acide aspartique, acide glutamique et glycine était sensiblement moindre chez les poissons d'eau de mer que chez les poissons d'eau douce. Il semble que le poisson puisse tirer de l'eau de mer du sodium, du potassium et du magnésium mais que le dépôt du calcium et du phosphore dans le corps soit réduit par la présence de ces minéraux dans le régime alimentaire

Estudios sobre las necesidades de nutrientes de la trucha arco iris, *Salmo gairdneri*, criada en aguas marinas y dulces

Extracto

Se han realizado algunos experimentos para determinar las diferencias fundamentales en la utilización de proteínas, lípidos y minerales entre la trucha arco iris criada en agua de mar y la criada en aguas dulces, se encontraron algunas diferencias significativas en la utilización de proteínas y lípidos. Para lograr índices máximos de crecimiento, aprovechamiento de los piensos y supervivencia en aguas marinas resultó necesario que la ración alimenticia contuviera aproximadamente un 50% de proteínas. La falta de ácidos grasos del tipo $\omega 3$ en la alimentación de los peces determinó una elevada mortalidad en los ejemplares criados en aguas marinas, pero no en los criados en aguas dulces. El porcentaje de amino-ácidos esenciales en el plasma no resultó notablemente afectado por la salinidad. En cambio, los porcentajes de taurina, β-alanina, ácido aspártico, ácido glutámico y glicina resultaron significativamente menores en los peces de agua salada que en los de agua dulce. Los peces pueden extraer sodio, potasio y magnesio del agua del mar, pero la acumulación de calcio y fósforo en el cuerpo se reduce si estos minerales están presentes en la ración alimenticia.

1 Introduction

Considerable research has been conducted on freshwater fish nutrition but studies on the nutrient requirements of salmonids grown in sea water are limited. In sea water, fish can probably absorb a number of minerals directly from the saline environment to meet their specific needs for growth and metabolism, and may not require addition of these minerals to the diet. Evidence indicates that physiological inter-relationships exist between minerals and nitrogen components of the diet (Savage, 1972). Furthermore, the adaptation of salmonids to hyperosmotic media involves changes in the energy cost of osmoregulation (Rao, 1968).

The protein and amino acid requirements of salmonids in sea water are not well understood. In fresh water, however, it has been shown that salmonids require the following amino acids in the diet: arginine, lysine, tryptophan, methionine, leucine, isoleucine, histidine, phenylalanine, valine and threonine (Halver, DeLong and Mertz, 1957). Zeitoun *et al* (1973) reported that the protein requirement of rainbow trout (*Salmo gairdneri*) increased with the increase in water salinity (10–20 ppt). They suggested that the optimum dietary protein level was important in protecting the internal environment of the fish against the hyper tonic external environment.

Freshwater and marine fish do not differ basically in their mechanisms for deposition, synthesis, and interconversion of fatty acids (Reiser *et al*, 1963), but there are significant differences in the fatty acid composition of the two groups. Ackman (1967) showed that freshwater fish contain more linolenic, linoleic and arachidonic fatty acids than does marine fish oil. Ackman also observed a greater concentration of C_{16} fatty acids in marine fish. Stansby (1967) suggested that the differences in fatty acid composition between freshwater and marine fish were due mainly to differences in the dietary intake of lipid.

It has been shown that fish cannot synthesize fatty acids of $\omega 3$ or $\omega 6$ series and thus, these must be provided in the diet. Castell *et al* (1972) demonstrated that rainbow trout require a dietary source of $\omega 3$ series fatty acids. The question of whether the requirement of $\omega 3$ series fatty acids is universal for all salmonids either in freshwater or marine environments has yet to be established. Many commercial feeds are comprised chiefly of vegetable products with little regard to supplementing linolenic-type fatty acids.

Similar to the data available for protein and lipid requirements, little information is available on energy, vitamin and

mineral requirements of salmonids in sea water. Most of the work on inorganic elements in fish has been limited to studies on toxicity and osmoregulatory functions. The mineral requirements are difficult to determine because of the exchange of ions from the water across the gill membranes and skin of fish. Moreover, many trace elements are required in very small quantities and it is difficult to design test rations free of the element under study.

The present work was designed primarily to determine the basic differences in protein and lipid utilization by rainbow trout grown in sea water and fresh water under similar conditions and using the same test diets. Changes in the plasma amino acid levels and mineral balance were also studied.

2 Materials and methods

Rainbow trout (*Salmo gairdneri*), approximately 11–13 cm in length, were distributed in 20 lots of 50 fish each. The weight of each lot was adjusted so that each lot contained an equal weight of fish. The fish were held in 0·91 m diameter circular aquaria. Fish in 10 aquaria were gradually acclimatized to sea water over three weeks. The water temperature was maintained between 15 and 16°C throughout the experiment in both salt water and fresh water. The salinity of the sea water was 32 ppt. Water temperature was monitored daily, and the pH, dissolved oxygen and total ammonia nitrogen measured periodically. A record of mortality was also maintained and dead fish were examined for gross abnormalities.

Following the saltwater adaptation and a two week adjustment period, duplicate lots of fish were fed each of the experimental diets for 12 weeks. The composition of the experimental diet was similar to that used by Zeitoun *et al* (1973), but with modifications. Diets 1–3 (Table I) contained herring oil and the test protein at levels ranging from 40 to 50% of the dry diet. Diets 4 and 5 contained 40–50% test protein and corn oil. Fish were fed all they would eat 3–4 times a day. They were group-weighed every 4 weeks. During the last week of the experiments, fish were fed the test diets containing 0·5% chromic oxide as an inert digestion indicator. Before faecal collection, fish were lightly anaesthetized by immersion in sea water containing MS-222 (ethyl m-aminobenzoate methanesulphonate). Faeces were collected from the rectal region by applying gentle pressure to the surface of fish. Faecal samples were freeze-dried, ground and analysed for nitrogen and chromic oxide.

At the beginning and end of the experiment, samples were taken to determine body composition. Carcass analyses were conducted in triplicate on a pooled sample of 10 fish for each tank after the fish had been frozen, ground, freeze-dried and then reground. After the final weight measurement, blood samples were taken for plasma amino acid analysis from fish which had been fed diets containing herring oil (diets 1–3).

Nitrogen in feed, faeces and carcass was determined on an automated Kjeldahl analyser (Technicon Instrument Co., Ltd.) according to the method of Ferrari (1960). The method of Bligh and Dyer (1959) was used for body lipid determination. Chromic oxide in feed and faeces was analysed according to the method of Arthur (1970). Body moisture and ash were estimated by the procedure of the Association of Official Analytical Chemists (AOAC) (1970). Ash samples were analysed for calcium, phosphorus, magnesium, sodium and potassium. Calcium and magnesium were determined using an SP90 atomic absorption spectrophotometer (Unicam Instruments Ltd.) according to the AOAC (1970) method. Sodium and potassium were measured on the atomic absorption spectrophotometer operating on emission. Phosphorus was determined by the method of Fiske and Subbarow (1925) and plasma amino acids were analysed on an automatic amino acid analyser (Beckman 120C).

Analyses of variance were made for the data obtained from this experiment and tests of significance were made using Duncan's multiple range at the 5% probability level as outlined by Steel and Torrie (1960).

3 Results and discussion

3.1 *Growth and feed efficiency*

The data presented in Table I clearly indicated that the growth of fish was significantly better in sea water than in fresh water for equivalent diets. Incorporation of 50%

TABLE I
THE PERFORMANCE OF RAINBOW TROUT FED VARIOUS EXPERIMENTAL DIETS FOR 12 WEEKS

	Diet number				
	1	*2*	*3*	*4*	*5*
	Dietary protein level (%) and source of lipids				
	40+ HO[a]	*45+ HO*	*50+ HO*	*40+ CO*[b]	*50+ CO*
Fresh water					
Average initial weight (g)	50·7	50·5	51·1	50·6	50·9
Average final weight (g)	92·6	94·3	103·7	93·7	99·1
Average weight gain (%)	82·6	86 7	102·9	85·2	94·7
Feed conversion ratio[c]	1·25	1·21	1·03	1·26	1·05
Digestibility of protein (%)	90·4	93·3	94·7	89·7	92·1
Mortality (%)	0	0	0	0	0
Sea water					
Average initial weight (g)	51·1	50·9	51·2	51·5	50·9
Average final weight (g)	94·9	104·5	118·8	95·9	112·9
Average weight gain (%)	85·7	105·3	132·0	86·2	121·8
Feed conversion ratio[c]	1·36	1·30	1·14	1·38	1·16
Digestibility of protein (%)	88·4	89·5	92·1	89·5	92·9
Mortality (%)	15·6	16·7	9·7	25·0	15·5

[a] HO = Herring oil
[b] CO = Corn oil
[c] Calculated as weight of feed/weight gained

protein in the diet resulted in a significant improvement of weight gain of fish fed either corn oil or herring oil in both fresh and salt water. The diet containing 45% protein produced a significant increase in weight gain over the 40% protein diet in sea water, but this response was not evident in fresh water. Saltwater fish fed the diet containing 50% protein and fish oil showed the maximum weight gain compared with any other group. The performance of fish fed the diet containing 40% protein was extremely poor, both in salt water and fresh water.

Overall feed conversion results showed that the saltwater fish had significantly higher feed intakes per unit of weight gain than freshwater fish for equivalent diets. The diet containing 50% protein showed better feed efficiency compared with the 40 and 45% protein diets, both in fresh water and in salt water. It appears that a minimum of 50% protein in the diet is essential for maximum weight gain and feed efficiency of rainbow trout reared in sea water on these test diets.

3.2 *Mortality*

Although there was no mortality of freshwater fish during the experiment, fish grown in sea water showed high mortalities (Table I). Autopsy of these fish revealed extensive inflammation of the digestive tract particularly the intestine. Histological examination showed hyperaemia and sloughing of intestinal epithelia.

Significantly more seawater fish died on the corn oil diet than on the herring oil diet. The high mortalities in experiments using corn oil were probably attributable to the lack of essential fatty acids ($\omega 3$ type fatty acids) in the diet. Evidence indicated that fish cannot synthesize fatty acids of $\omega 3$ series, and that these fatty acids must be incorporated in the feed. The presence of $\omega 3$ type fatty acids in the diet seems to be more critical in salt water than in fresh water.

Results also indicate that mortalities were significantly lower in the group fed 50% protein than those receiving 40% and 45% protein. This is in agreement with the findings of Zeitoun *et al* (1973) that a higher level of protein is required in the diet to protect the fish in salt water against the hypertonic external environment.

3.3 *Digestibility of protein*

The apparent digestibility of dietary protein decreased significantly with the increase in salinity (*ie*, fresh water versus salt water) for fish fed herring oil (Table I). This decrease was consistent with all three levels of protein. However, such decreases in protein digestibility were not observed for fish receiving the corn oil diet.

There was an improvement in the digestibility of protein with the increase in the level of protein. This increase was probably due to the lower level of carbohydrate (dextrin) in the high protein diets. Kitamikado, Morishita and Tachino (1964) observed that incorporation of a high level of starch in test diets reduced the digestibility of protein.

3.4 *Body composition*

The effects of feeding different diets on body composition of rainbow trout held in fresh water and salt water are shown in Table II. Generally, the moisture, lipid, and ash contents of fish were not significantly influenced by salinity. However, a higher carcass protein level was noted in fish grown in salt water than in those reared in fresh water.

Both freshwater and saltwater fish fed 50% protein showed higher carcass lipid and lower moisture levels than fish receiving 40% and 45% protein. On the other hand, protein level was not affected by the increase in dietary protein level. Ogino and Saito (1970) also observed that in common carp (*Cyprinus carpio*) the accumulation of protein in the body reached a maximum value when the dietary protein level was about 38%, but the body weight increased up to the highest level of protein used (55%). It appears that rainbow trout convert additional protein to body fat.

3.5 *Plasma amino acid level*

Plasma amino acid data (Table III) indicate that a higher concentration of taurine was present in freshwater fish than in marine fish fed similar test diets. The biochemical significance of this compound is unknown. Chance (1962) reported that the level of taurine was very high in the plasma of spawning male chinook salmon (*Oncorhynchus tshawytscha*) in fresh water but low in young salmon migrating to the ocean. Cowey, Daisey and Parry (1962) reported that the taurine level was high in the plasma of migrating Atlantic salmon (*Salmo salar*) in both fresh water and salt water. Parry (1970) failed to demonstrate an osmoregulatory function for taurine.

Glycine, glutamic acid, aspartic acid and β-alanine levels were also lower in saltwater than in freshwater fish. The concentration of essential amino acids except leucine and isoleucine were not affected by the salinity. Both isoleucine and leucine were low in freshwater fish. In general, no

TABLE II

MOISTURE, PROTEIN, LIPID AND ASH CONTENT OF RAINBOW TROUT FED VARIOUS EXPERIMENTAL DIETS IN FRESH AND SALT WATER FOR 12 WEEKS

Treatment	*Moisture* (%)	*Protein* (%)	*Lipid* (%)	*Ash* (%)
Initial	75·3 ± 0·21[a]	14·9 ± 0·33	7·5 ± 0·27	2·35 + 0·12
	Fresh water			
Herring oil +40% protein	72·3 ± 0·06	15·3 ± 0·26	9·9 ± 0·29	2·54 ± 0·05
+45% protein	72·3 ± 0·48	15·4 ± 0·19	9·7 ± 0·49	2·58 ± 0·08
+50% protein	70·7 ± 0·28	15·2 ± 0·11	11·6 ± 0·20	2·44 ± 0·02
	Sea water			
Herring oil +40% protein	71·6 ± 0·05	16·0 ± 0·27	9·8 ± 0·28	2·60 ± 0·06
+45% protein	71·3 ± 0·09	15·9 ± 0·23	10·2 ± 0·24	2·58 ± 0·07
+50% protein	70·9 ± 0·34	16·6 ± 0·21	11·0 ± 0·38	2·54 ± 0·06

[1] Mean ± standard error

consistent plasma amino acid pattern was noted in either freshwater or saltwater fish with the increase in level of dietary protein.

A large turnover of salt and other minerals takes place in marine fish through the body surface and gut. Evidence indicates that a physiological inter-relationship exists between minerals and the nitrogen components of a diet. Savage (1972) indicated that cellular concentrations of alkali minerals, especially potassium and sodium, have specific effects on protein and amino acid metabolism in chicks. It is possible that the high turnover of minerals in the marine environment may affect the amino acid metabolism and increase the requirement of certain amino acids in fish. This would also explain the high protein intake of saltwater fish. To date, no systematic study has been done on the intermediary metabolism of amino acids in fish.

3.6 *Mineral composition*

The mineral composition of fish carcasses is shown in Table IV. Results indicate that calcium and phosphorus levels were lower in saltwater fish than freshwater fish, whereas magnesium, sodium and potassium levels were higher in fish grown in salt water. The level of dietary protein had no significant effect on the mineral composition of fish.

It seems probable that fish can derive a number of minerals from the sea water to satisfy the specific mineral needs for growth and metabolism. Some workers (Templeton and Brown, 1963; Ichikawa and Oguri, 1961) have reported that calcium and phosphorus are absorbed and excreted through the gill membrane of fish, but phosphate is more efficiently absorbed from the intestinal tract (Philips, 1959). Yone, Sakamoto and Furuichi (1974) have demonstrated that deletion of calcium from the diet did not affect the growth of seabream (*Pagrus major*). It is possible that the calcium present in a diet may affect the absorption and excretion of both calcium and phosphorus and consequently affect their retention in the body. At present, further experiments are in progress to investigate in more detail the mineral utilization by salmonids held in sea water.

More information is required on protein, amino acid, lipid, mineral and vitamin requirements of fish grown in marine environments before it is possible to incorporate the desired elasticity in feed formulation. Salmonids have requirements for individual nutrients on a daily basis which are related to water temperature, body weight and salinity, *etc.* Therefore, it is essential to work out feeding guides taking these factors into account for various stages of development. The overall metabolism of fish, which is

TABLE III

EFFECT OF DIETARY PROTEIN LEVEL ON PLASMA AMINO ACID CONTENT OF RAINBOW TROUT IN FRESH WATER AND SEA WATER

Amino acid	*Protein level*					
	Fresh water			*Sea water*		
	40	*45*	*50*	*40*	*45*	*50*
	(μ moles/ml of plasma)					
Taurine	3 723	3 690	3 819	1·428	1·660	1 542
Aspartic acid	0 238	0 259	0 198	1 177	0·152	0·109
Threonine	0·441	0·465	0·465	0 540	0·493	0·512
Serine	0·550	0 622	0 584	0·515	0·385	0·385
Asparagine and/or glutamine	0·455	0·468	0·507	0 529	0 424	0·411
Proline	1·290	1·512	1·400	1·229	0·948	1·062
Glutamic acid	0·751	0·894	0 842	0·536	0·521	0·569
Glycine	3·190	2·979	3·063	1 779	1 601	1·645
Alanine	1 096	0·997	1·092	1 204	1 184	0 919
α amino-n-butyric acid	0·032	0·040	0 052	0·042	0·031	0·032
Valine	1 062	1·045	1·035	1·000	0·984	1·059
Methionine	0·165	0 214	0 185	0 219	0 182	0·263
Isoleucine	0·337	0·389	0·376	0·415	0·434	0 509
Leucine	0·625	0·733	0 734	0 820	0·812	0·902
Tyrosine	0 179	0·209	0 207	0·255	0·212	0 216
Phenylalanine	0·199	0·235	0·245	0·287	0·226	0·240
β-alanine	0 195	0 185	0·207	0·107	0·081	0·039
Lysine	0 586	0·633	0·657	0·664	0·564	0·617
Histidine	0·156	0 172	0·159	0·182	0·169	0·185
Arginine	0·250	0·256	0·197	0 234	0·208	0·203

TABLE IV

MINERAL COMPOSITION OF RAINBOW TROUT FED DIFFERENT DIETS IN FRESH WATER AND SALT WATER AFTER 12 WEEKS

Treatment	*Calcium*	*Phosphorus*	*Magnesium*	*Sodium*	*Potassium*
	(*mg/g of carcass*)				
	Fresh water				
Herring oil +40% protein	5·59 ± 0·04[a]	4·66 ± 0·08	0·27 ± 0·01	0·76 ± 0·04	2·09 + 0·13
+45% protein	5·53 ± 0·10	4·70 ± 0·14	0·29 + 0·01	0·75 ± 0·04	2·19 ± 0·06
+50% protein	5·27 ± 0·12	4·66 + 0·06	0·26 ± 0·01	0 74 ± 0·02	2·17 ± 0·06
	Sea water				
Herring oil +40% protein	5·00 ± 0·26	4·60 ± 0·09	0·38 ± 0·01	0·87 + 0·04	2·62 + 0·08
+45% protein	4 86 ± 0·22	4·36 ± 0·15	0·36 ± 0·00	0·84 ± 0·04	2·54 ± 0·10
+50% protein	4·84 ± 0·09	4·32 ± 0·08	0·36 + 0·01	0·85 ± 0·08	2·63 ± 0·14

[a] Mean ± standard error

closely related to their nutrition, is not presently understood. There is also a distinct possibility that fish in the marine environment have requirements for certain nutrients which are as yet unidentified.

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Recent Advances in Studies on Mineral Nutrition of Fish in Japan

T. Nose and S. Arai

Abstract

Recent studies in Japan on mineral requirements of selected fish species are reviewed. Each species of fish was found to have specific requirements for dietary minerals. Due to their capability to take in dissolved calcium from environmental water, most of the fish studied except eels grew satisfactorily on purified test diets not supplemented with calcium, provided an adequate amount of dietary phosphorus was incorporated in the diet. Dietary phosphorus was found to be indispensable for growth of all the fishes studied so far, and requirements for magnesium and iron in the diet were also determined for several species of fish

There are some indications that a supplement of minerals is effective in improving practical diets. Calcium added to either a hydrocarbon yeast diet or a methanol yeast diet improved growth of rainbow trout and carp respectively. Enrichment of a fish meal diet with a mineral mixture increased the growth rate and feed efficiency of eels. Commercial diets fortified with phosphorus remarkably accelerated the growth of carp. Phosphorus was also found to exert a profound influence on carp by lowering the lipid content of the body, especially of the viscera Thus, the role of minerals in fish nutrition should be studied more extensively in order to formulate more efficient fish feeds as well as to improve the quality of test diets

Progrès récents des études sur les sels minéraux dans l'alimentation des poissons au Japon

Résumé

Les récentes études menées au Japon sur les besoins en sels minéraux de certaines espèces de poissons sont rapidement examinées. Il est constaté que chaque espèce de poisson a des besoins en sels minéraux spécifiques Parce qu'ils sont capables de prélever le calcaire dissous dans l'eau ou ils évoluent, la plupart des poissons étudiés, sauf l'anguille, se développent de façon satisfaisante avec une alimentation expérimentale purifiée sans complément de calcium, à condition qu'une quantité suffisante de phosphore soit incorporé dans leur alimentation. Le phosphore s'est révélé indispensable à la croissance de tous les poissons étudiés jusqu'à présent, et les besoins en magnésium et en fer ont également été déterminés pour plusieurs espèces.

Il semble, d'après certains indices, qu'un complément de sels minéraux est efficace pour améliorer l'alimentation pratique. Le calcium ajouté à une alimentation à base de levure d'hydrocarbure ou de méthanol améliore la croissance respectivement de la truite arc-en-ciel et de la carpe. L'enrichissement de l'alimentation des poissons à l'aide d'un mélange de sels minéraux accroît le taux de croissance et l'efficacité nutritive chez les anguilles Les rations commerciales fortifiées au phosphore accélerent remarquablement la croissance des carpes. Le phosphore s'est également revele exercer une influence profonde sur la carpe par l'abaissement de la teneur en lipides du corps, et plus spécialement des viscères. Ainsi, le rôle des sels minéraux dans l'alimentation des poissons devrait être étudié de façon plus approfondie afin de permettre la formulation d'aliments plus efficaces pour le poisson ainsi que d'améliorer la qualité des régimes expérimentaux

Ultimos progresos en los estudios realizados en el Japón sobre la presencia de elementos minerales en la alimentación de los peces

Extracto

Se examinan brevemente los estudios realizados recientemente en el Japon sobre las necesidades de minerales de algunas especies de peces. En dichos estudios resultó que cada especie tiene necesidades especificas de elementos minerales Gracias a su capacidad de absorber el calcio disuelto en el agua en que viven, la mayor parte de los peces estudiados, con excepción de la anguila, crecieron satisfactoriamente con raciones purificadas de ensayo, no suplementadas con calcio, a condición de que se hubiera incorporado en su ración alimenticia una cantidad suficiente de fósforo dietético. El fósforo dietético resultó indispensable para el desarrollo de todos los peces estudiados. Se determinaron también las necesidades de magnesio y hierro de varias especies de peces.

Hay varios indicios de que el empleo de elementos minerales para mejorar la ración alimenticia resulta eficaz. Añadiendo calcio a una ración de levaduras hidrocarbonadas o levaduras metanólicas se logró mejorar el crecimiento de truchas arco iris y carpas, respectivamente. Enriqueciendo una ración a base de harina de pescado con una mezcla de elementos minerales se consiguió aumentar el ritmo de crecimiento de las anguilas y su aprovechamiento de los alimentos. El empleo de raciones comerciales reforzadas con fósforo permitió acelerar notablemente el crecimiento de las carpas. También resultó que el fósforo ejerce una profunda influencia en la carpa, reduciendo el contenido de lipidos del cuerpo, especialmente de las vísceras. Así pues, es necesario estudiar más a fondo la función de los elementos minerales en la nutrición de los peces en orden a preparar piensos más eficaces y mejorar la calidad de las raciones de ensayo.

1 Introduction

Fish have the ability to absorb inorganic elements from the

surrounding water as well as from their diet. This ability to exchange inorganic ions across not only the gill membranes but also the body surface makes it difficult to elucidate the nutritional function of dietary minerals. Ions absorbed from the external medium have nutritional and osmoregulatory implications, and the interdependence of both functions complicates any study on the uptake and excretion of inorganic elements in fish. Most studies on metabolism of minerals in fish have been connected with osmoregulation, and the nutritional aspects have been rather neglected. In recent years, however, the importance of minerals as nutrient has been emphasized by Japanese scientists, as reviewed in this paper.

2 Effects of supplementing mineral mixture in purified test diets

The effects of adding a mineral mixture to purified test diets on growth of fish have been recently investigated in several species of fish. Most of the fish were found to require a certain amount of mineral mixture in their purified test diets for good growth.

When raised on a purified test diet lacking a mineral mixture, rainbow trout (*Salmo gairdneri*) were observed to lose their appetite and become sluggish within two weeks. More than 10% of the fish died after suffering from convulsions by the end of a 50 day experimental period (Ogino and Kamizono, 1975). At the end of the experiment, most of the surviving fish showed scoliosis, lordosis, and cranial deformity characterized by a round and shortened snout. The erythrocyte counts and growth were affected by the level of dietary minerals. For maximum growth, the mineral mixture (McCollum salt mixture No. 185, fortified with trace metals) at a 4% level was concluded to be adequate. A similar result was obtained in the Freshwater Fisheries Research Laboratory, Hino, Tokyo (Nose, 1972). When rainbow trout fry were kept on a casein-gelatin diet, they showed normal growth rate on a mineral mixture-free diet for the first 10 weeks, but thereafter loss of appetite, depression of growth, and hypochromic microcytic anaemia were observed (Tables I and II). The minimum level of supplemental mineral mixture was postulated to be 2%. These results suggest that rainbow trout can absorb the dissolved minerals from the environment to a limited degree but need the supply of dietary minerals, unlike the findings of Wolf (1951) that rainbow trout maintained good growth for 23 weeks on a synthetic diet not supplemented with any mineral mixture. The discrepancy between these experiments might be attributable to the mineral concentrations in the experimental water used.

Common carp (*Cyprinus carpio*) were found to be not as sensitive to the depletion of dietary mineral mixture (Ogino and Kamizono, 1975). No apparent signs of deficiency were found in carp raised on a diet lacking salt mixture within an experimental period lasting for 50 days, and the haemoglobin contents were normal. Addition of mineral mixture up to 4% resulted in a little improvement in growth rate, and further addition of mineral mixture resulted in slightly depressed growth.

TABLE I
THE RESULTS FOR A 20 WEEK FEEDING EXPERIMENT ON RAINBOW TROUT WITH DIETS CONTAINING DIFFERENT LEVELS OF MINERAL MIXTURE

Level of mineral mixture (%)	*Lot number*	*Average body weight*		*Mortality* (%)	*Feed efficiency* (%)	*Feeding rate* (%)
		Initial (*g*)	*Final* (*g*)			
0	1	0·83	13·3	9	95·9	1·83
	2	0·83	13·3	8	92·2	1 92
1	3	0·85	17 6	2[a]	91·7	2 20
	4	0·82	16 7	1[a]	89 6	2 20
2	5	0·84	18 5	0	89·1	2·51
	6	0·83	20·2	2[a]	86·8	2 58
4	7	0·83	19·6	0	81·5	2·66
	8	0·83	20 0	0	83 1	2·69
6	9	0·85	19·3	0	81 7	2·62
	10	0·81	17 0	1[a]	79 5	2 61

[a] Fish died within the first two weeks
Note: The basic diet was the same as that reported by Halver (1957) except that USPXII salt mixture No 2 with trace metals was replaced by cellulose powder

The supplemental effect of mineral mixture on growth of Japanese eels (*Anguilla japonica*) has been examined by Arai, Nose and Hashimoto (1971). The optimum level of mineral mixture was found to be approximately 8% (Fig. 1), being more than twice the requirement of rainbow trout. Eels developed loss of appetite and cessation of growth within two weeks followed by a gradual loss of their body weight and high mortality, when they were raised on the diets either lacking mineral mixture or containing 1% mineral mixture.

Each species of fish thus shows a specific response to mineral mixture supplemented by purified test diets. This can be attributed to their different abilities to absorb minerals from environmental water and to retain absorbed minerals from the diet within their body.

3 Calcium and phosphorus requirements

Calcium and phosphorus are the most abundant inorganic elements in the animal body and 99% of calcium and 80% of phosphorus are located in skeletal tissues. These two inorganic elements have been demonstrated to play an important role in fish nutrition.

Cranial deformity, associated with other disorders of the skeleton, occurred in young hatchery-reared carp receiving

TABLE II
HAEMATOLOGICAL VALUES OF EXPERIMENTAL FISH FED DIFFERENT LEVELS OF MINERAL MIXTURE AT THE END OF A 20 WEEK FEEDING EXPERIMENT

Level of mineral mixture (%)	*Number of samples*	*Erythrocyte count* (10^4/mm^3)	*Haemoglobin* (*g*/*100 ml*)	*Haematocrit* (%)	*MCHC*[a]	*MCV*[b] (μ^3)	*MCH*[c] (*10* ^{9}*mg*/*cell*)
0	5	1 545	7·45	34 3	21·8	239	52·0
1	3	1 336	8·98	38·2	23·5	286	67·2
2	3	1 401	9·15	41·3	22·1	295	65·4
4	3	1 475	9·02	39 7	22·7	270	61·1

[a] Mean corpuscular haemoglobin concentration
[b] Mean corpuscular volume
[c] Mean corpuscular haemoglobin

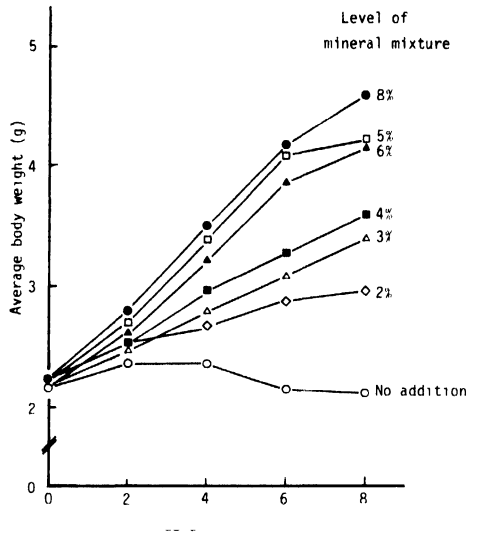


Fig 1. Supplemental effect of mineral mixture on growth of eel. The mineral mixture used was USP XII, salt mixture No 2 with trace metals (Arai, Nose and Hashimoto, 1971)

a formulated commercial diet or other dry feeds. It has been shown by Murakami (1967) that the disease was prevented or healed effectively by the addition of 5% calcium monohydrogen phosphate or McCollum salt mixture in the diet.

Recently, both common carp and rainbow trout were demonstrated to show good growth on a purified test diet containing calcium as low as 30 mg/100 g, if an adequate amount of phosphorus was provided in the diet (Ogino and Takeda, 1974, 1974a). Thus, both species seem to be able to absorb the requisite amount of calcium from environmental water containing calcium at 16 to 20 ppm. On the other hand, carp and rainbow trout were clearly shown to require dietary phosphorus. In experiments with a diet devoid of supplemental phosphorus, fish grew poorly and there was high mortality in both species. Other signs of deficiency, such as lordosis, deformed cranial bone, and decalcification were recognized in carp, and symptoms such as poor appetite, sluggish movement, retarded growth and low calcium and phosphorus content in the body were observed in rainbow trout. The optimum level of phosphorus for growth was estimated to be within the range 600–750 mg/100 g of diet for carp and 650–1 090 mg/100 g for trout (Ogino and Takeda, 1974, 1974a). Dietary calcium level had no effect on the requirement of phosphorus in both species. When carp were fed a low calcium and high phosphorus diet, active absorption of calcium from the environmental water was detected, and the increased level of dietary phosphorus accelerated the deposition of both calcium and phosphorus in the body.

In the case of eels, a diet deficient either in calcium or in phosphorus resulted in poor appetite and depression of growth of the fish, and the growth increased in proportion to the dietary level of calcium and phosphorus (Fig. 2). The requirements of eels for calcium and phosphorus were assumed to be 270 mg and 290 mg/100 g in dry diet, respectively (Arai, Nose and Hashimoto, 1975a). Thus, the dietary requirements of eels differ from those of both carp and rainbow trout in being lower for phosphorus and higher for calcium.

Dietary phosphorus level was also found by Sakamoto and Yone (1973) to affect the growth of red seabream (*Pagrus major*). Low dietary phosphorus resulted in low growth rate. The optimum amount of dietary phosphorus for growth was 680 mg/100 g when dietary calcium was adjusted to 340 mg/100 g and seemed to become higher in the presence of excess dietary calcium. Dietary calcium was

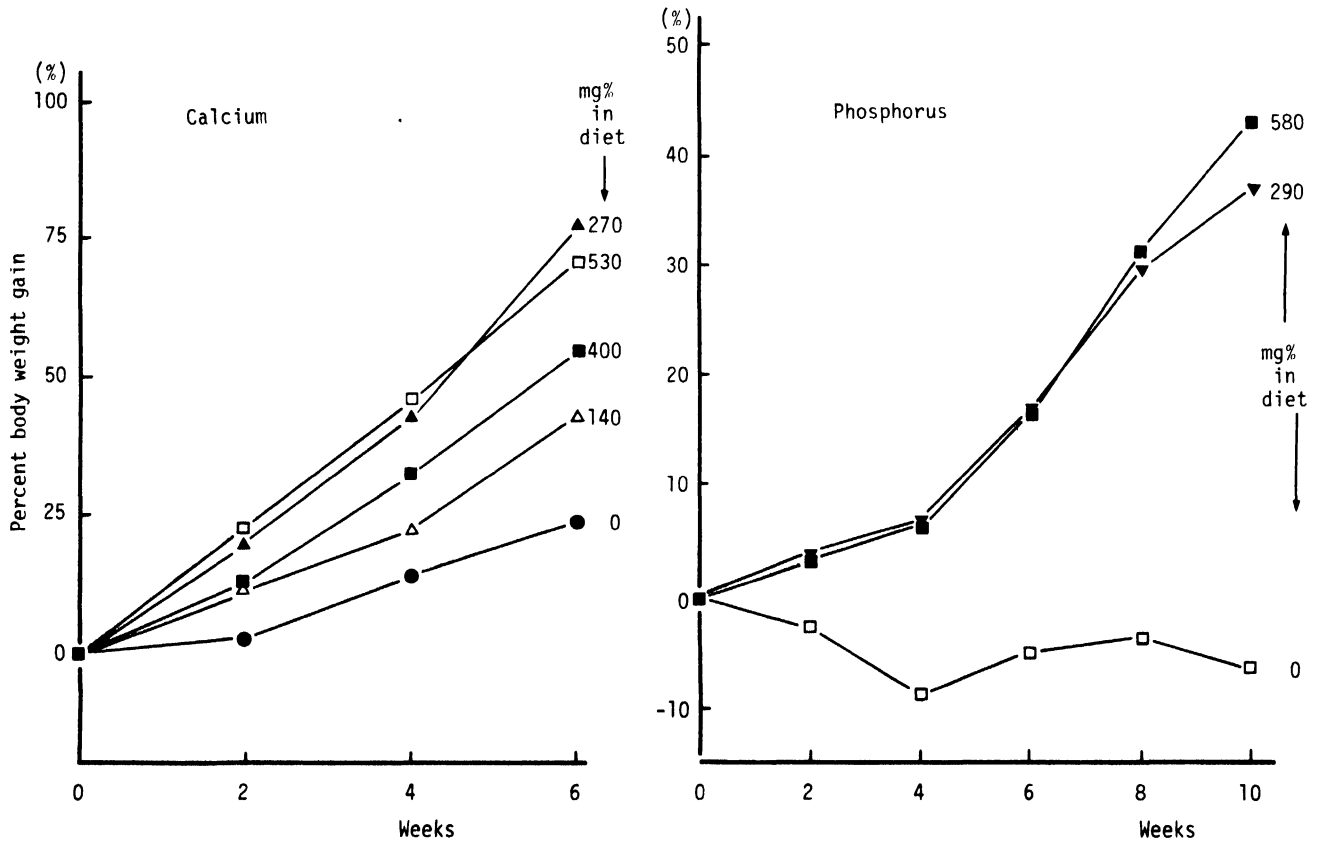


Fig 2. Effects of dietary level of calcium and phosphorus on growth of eel (Arai, Nose and Hashimoto, 1975)

demonstrated to be unessential for maximum growth, indicating that the fish can take up the required amount of calcium from the environmental sea water (Sakamoto and Yone, 1973c).

4 Availability of phosphorus in feeds

Phosphorus exists in various forms in feed components, with some forms being chemically stable and hardly utilizable by fish. It is desirable, therefore, to obtain data on the availability of phosphorus in feed components in order to formulate efficient fish feeds.

The availability of phosphorus in several feed components for carp and rainbow trout has been examined by using the method devised for determination of digestibility of nutrients (Takeda and Ogino, 1975). As shown in Table III, monobasic calcium phosphate is fairly well absorbed by these two species of fish. On the other hand, tribasic calcium phosphate is absorbed only slightly by carp, but extensively by rainbow trout. Tribasic calcium phospate seems to become more soluble at the low pH in the stomach of trout and is much more easily absorbed than in common carp, which lack a stomach. Phosphorus in casein and hydrocarbon yeast is almost completely absorbed by both species, suggesting that phosphorus combined with either protein or nucleic acid is highly accessible.

A considerable difference is observed between common carp and rainbow trout with respect to their ability to absorb phosphorus in fish meal. Rainbow trout can utilize 60% of total phosphorus in the meal, while carp utilize only 25%. This low utilization level of phosphorus in fish meal by carp is due to the fact that a greater part of the phosphorus is contained in bony tissues as insoluble tribasic calcium phosphate. Phosphorus in activated sludge is also absorbed more easily by rainbow trout than carp, while that in rice bran is absorbed by carp a little more easily than by rainbow trout.

TABLE III
AVAILABILITY OF PHOSPHORUS IN SEVERAL FEED COMPONENTS FOR RAINBOW TROUT AND COMMON CARP (TAKEDA AND OGINO, 1975)

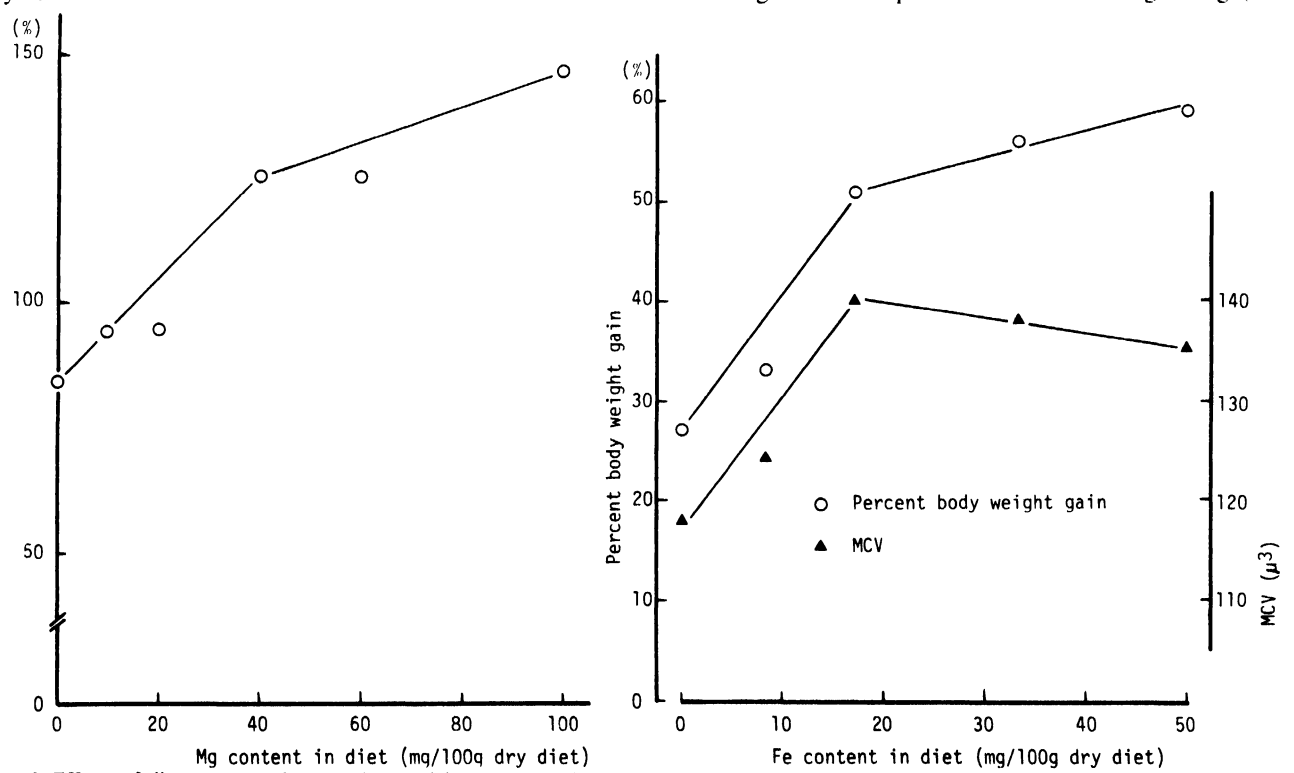
Sources	*Phosphorus contents in test diet* (%)	*Availability*	
		Common Carp (%)	*Rainbow trout* (%)
Tribasic calcium phosphate	0·65	3	51
Monobasic calcium phosphate	0·79	80	65
Phytin	1·65	8	19
Casein	0 47	106	90
Fish meal[a]	0·99	26	60
Hydrocarbon yeast[a]	0 46	99	91
Wheat germ[a]	0·58	57	58
Activated sludge[a]	0 84	12	49
Rice bran[a]	0·79	25	19

[a] Defatted and heat treated

5 Other minerals

In freshwater fish, the amount of dietary magnesium was found to have a significant effect on growth and magnesium deficiency was experimentally induced in rainbow trout, common carp and eel.

Rainbow trout kept on a magnesium-free diet showed poor appetite, extraordinarily low growth, convulsions, and deformities. The fish on diets having more than 25 mg/100 g of magnesium, however, showed no signs of deficiency. Maximum growth was attained at 60–70 mg/100 g magnesium in the diet (Chiou and Ogino, 1976). Common carp also developed depression of appetite, sluggish movement, convulsions and spasmodic swimming at the end of a 10 day feeding on a magnesium-free diet, and high mortality was recorded. From the growth and contents of magnesium and calcium in the body, the minimum requirement for dietary magnesium was estimated to range from 40 to 50 mg/100 g (Chiou and Ogino, 1976). Eels showed no specific signs of magnesium deficiency except poor appetite and slower growth, and the minimum dietary level to sustain growth was postulated to be 40 mg/100 g (Arai,



g 3. Effects of dietary level of magnesium and iron on growth of eel (Arai, Nose and Hashimoto, 1975, 1975a)

Nose and Hashimoto, 1975) (Fig. 3). The amount of magnesium required by these freshwater fishes, therefore, does not vary significantly from species to species. The red seabream, on the other hand, did not require dietary magnesium (Sakamoto and Yone, 1973b).

A diet deficient in iron resulted in hypochromic microcytic anaemia when fed to eels (Arai, Nose and Hashimoto, 1975a) (Table IV), yellowtail, *Seriola quinqueradiata*, (Ikeda, Ozaki and Umematsu, 1973), and red seabream (Sakamoto and Yone, 1974). The dietary requirement of eel for iron was postulated to be 17 mg/100 g in dry diet (Fig. 3).

6 Supplemental effects of minerals in formulated feeds

Most formulated fish feeds commercially available in Japan are compounded with a large amount of white fish meal which results in a high level of crude ash in the feeds. Commercial diets for eel, for example, contain 14–16% crude ash, which includes approximately 20% calcium and 15% phosphorus. A large portion of these two elements is, however, located in bones as water insoluble salts. Since most of the water soluble minerals are removed during the processing of fish meal, the mineral composition of fish meal is considerably different from that of the original raw fish ingredient. The supplement of minerals should, therefore, be considered for the maintenance of good growth and health, especially for eels which show a higher requirement for calcium.

The supplement of a mineral mixture to a fish meal diet was found to enhance growth of eels (Arai, Nose and Kawatsu, 1974). Twice as much growth was recorded for the fish receiving the diet with 2% USP XII salt mixture No. 2 plus trace metals (see Halver, 1957) when compared to those on a mineral mixture-free diet (Fig. 4). Haematological examination showed signs of hypochromic microcytic anaemia in the fish kept on a diet lacking the mineral mixture. Another experiment showed that a combination of calcium carbonate, magnesium sulphate and ferric citrate in the proportion of 50, 40 and 10 in weight was found to be equivalent to USP XII salt mixture No. 2 in sustaining growth when added to a fish meal diet (Table V). The supplement of sodium biphosphate did not enhance, but depressed growth (Arai, unpublished data). These results indicate that some of the minerals are insufficient for eels, even if a large amount of fish meal is incorporated in their diets, and three elements, calcium, magnesium and iron, seem to be critical for their growth.

Yeast grown on hydrocarbon is considered to be an effective substitute for fish meal in formulated fish feeds. This yeast has particular mineral components, being high in

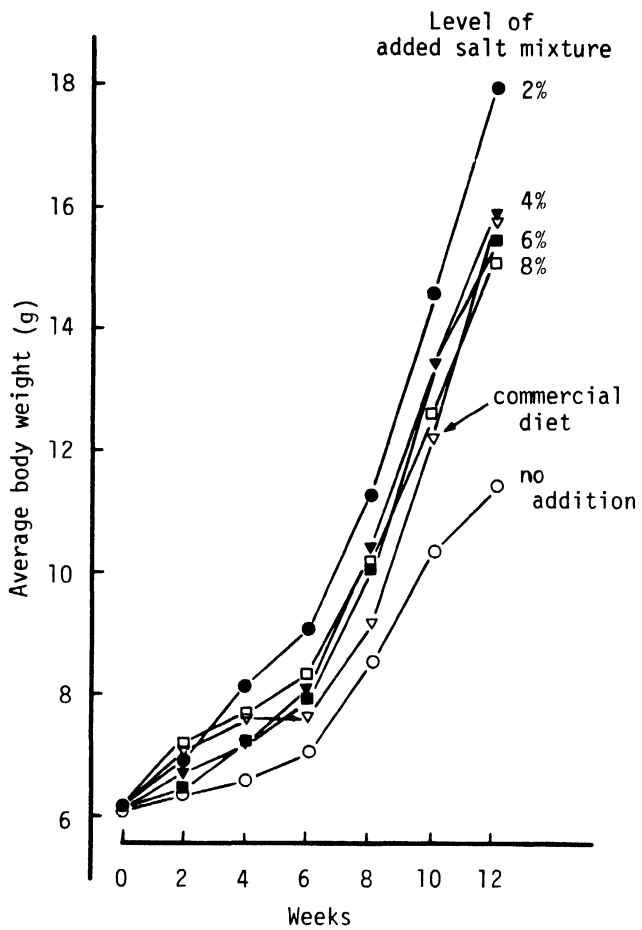


Fig 4. Effect of mineral mixture added to a fish meal diet on growth of eel (Arai, Nose and Kawatsu, 1974)

phosphorus and low in calcium. Addition of calcium to the yeast diet to approximately 250 mg/100 g stimulated the growth of rainbow trout (Arai *et al*, 1975). A similar result was reported by Takeuchi and Ishii (1975) in that supplementing dietary calcium at the level of more than 740 mg/100 g improved growth of carp raised on a diet composed of 70% yeast grown on methanol. As mentioned above, rainbow trout and carp seem to obtain as much calcium as they need from the surrounding water and require little dietary calcium, if any. These contradictory results indicate that the requirements of minerals in fish is a complex subject and further studies are necessary to elucidate mineral metabolism in fish.

The supplement of phosphorus to commercial carp diets was found by Murakami (1970) to be effective not only for prevention of cranial deformity but also for promotion of

TABLE IV
HAEMATOLOGICAL VALUES OF EEL RAISED ON DIETS HAVING DIFFERENT LEVELS OF FERRIC CITRATE

Iron level (mg/100 g)	*Erythrocyte count (×10/³mm⁻¹)*	*Haemoglobin (g/100 ml)*	*Haematocrit (%)*	*MCHC*[a]	*MCV*[b] *(μ³)*	*MCH*[c] *(10⁻⁹mg/cell)*
0·3	2 121	7·39	25·0	29·5	118	34 8
8·3	2 411	8·80	30·0	29·4	124	36·5
16·7	2 031	8·27	28 2	29·4	140	41 1
33·4	2 376	9·68	32·8	29·5	138	40 8
50·0	2 360	9·21	31·8	29·1	135	39·1

Note: These figures are the average of three samples
[a] Mean corpuscular haemoglobin concentration
[b] Mean corpuscular volume
[c] Mean corpuscular haemogolobin

TABLE V
EFFECT ON GROWTH OF EELS OF TWO KINDS OF MINERAL MIXTURE SUPPLEMENTED TO A FISH MEAL DIET[a]

Mineral mixture	Levels in diet (%)	Number of fish	Average body weight		Body weight gain (%)	Feed efficiency (%)	Mortality (%)
			Initial (g)	Final (g)			
USP XII, salt mixture plus trace metals	0	45	2·65 ± 0·11[b]	3·08 ± 0·20	16[b]	—	33 3
	2	45	2·70 ± 0·12	5·77 ± 0·30	114	32	0
Combination of							
$CaCO_3$ 50	1	40	2·73 ± 0·09	4·57 ± 0·40	67	21	0
$MgSO_4.7H_2O$ 40	2	40	2·76 ± 0·10	5·83 ± 0·30	111	34	0
Ferric citrate 10	3	40	2 73 ± 0·10	5·85 ± 0·32	114	30	0

[a] The experiment was conducted for 8 weeks at 25°C. The composition of basal diet white fish meal 72, dextrin 6, CMC 9, vitamin mixture 4, and cellulose powder 4 The mineral mixture was added in replacement of cellulose powder
[b] Standard error

growth. As shown in Table VI, addition of sodium monohydrogen phosphate at a 4% level resulted in remarkably improved growth rate and feed efficiency. The survival rate in wintering was also ameliorated. Phosphate supplementation was also considered effective in a diet containing 40% silkworm pupae as well as in commercial diets, especially during the summer.

TABLE VI
SUPPLEMENTAL EFFECT OF SODIUM MONOHYDROGEN PHOSPHATE TO A FISH MEAL DIET ON GROWTH AND LIPID CONTENT OF COMMON CARP (MURAKAMI, 1970)[1]

Na_2HPO4 added to diet (%)	Body weight gain (× 100%)	Feed efficiency (%)	Survival rate during wintering (%)	Lipid contents	
				Muscle (%)	Viscera (%)
0	8·0	61 7	70 3	6 5	13 5
2	9 8	69 0	73 7	5 2	5·2
4	10 8	79 4	76 6	5 2	8 3
6	10·0	68 0	78·0	4·6	5 7
8	9 8	66 7	69 0	4·3	6 4

[1] Feeding period 1 August-12 November 1969 (104 days) Initial body weight 1 7–2 0 g Basic diet white fish meal 60, wheat flour 36, vitamin mixture 1, McCollum salt No 185 1, and $CaCO_3$ 1

Murakami (1970) further pointed out that the lipid contents of muscle and viscera were remarkably reduced by the addition of phosphate to the diet, and protein contents of fish tissues consequently increased. This suggests the imporant role of phosphorus in catabolic metabolism of lipids resulting in high retention of protein in the fish body. Decrease of lipid in the liver of red seabream by the increment of dietary phosphorus was also observed by Sakamoto and Yone (1973a).

7 Discussion

It has been established that fish derive inorganic elements from the surrounding water as well as from diets and that a dual source of minerals is, therefore, available to fish. Some minerals are more easily absorbed by fish from environmental water. Nearly a thousand times more dissolved calcium was found to be absorbed by brook trout (*Salvelinus fontinalis*) kept in water containing 50 ppm of calcium and 1 ppm of phosphorus (Phillips *et al*, 1958). Therefore, the contribution of dissolved minerals as nutritional elements for fish depends largely on the capability of fish to take up dissolved minerals from the water.

Owing to this high ability of fish for active calcium intake, and also to the abundance of calcium in water, dietary calcium was found to be dispensable for all the fish species studied except eel. A strict requirement of eel for dietary mineral mixture and their inability to absorb chloride from the surrounding water (Krogh, 1937) suggest that the mineral metabolism of eel is considerably different from that of trout and carp.

Phosphorus is generally scarce in both fresh water and sea water when compared with other inorganic elements. Due to the low ability of fish to absorb phosphorus from the water, phosphorus may be the most limiting inorganic element for growth of fish. In recent studies, this has been verified by feeding experiments indicating that dietary phosphorus is essential for growth in all fish species studied. In addition, dietary phosphorus was found to affect lipid content of carp, suggesting a close metabolic interrelationship between phosphorus and lipid. It may be worth determining whether the phosphorus contents of commercial feeds have any connexion with fattiness of cultured fish.

Magnesium is closely associated with calcium and phosphorus in its distribution and metabolism. In some freshwater fishes, magnesium was demonstrated to be indispensable for growth. Very few studies have been devoted to metabolic interrelationship between calcium, phosphorus and magnesium, though low dietary magnesium was recently reported to induce elevation of calcium contents in the kidney of rainbow trout with the indication of renal calcinosis (Cowey, 1976). There are several reports concerning the effects of minor or trace elements supplemented to diets on growth of fish. Further studies, however, would be needed to quantify the requirements of these elements.

The mineral mixtures being used in fish nutrition studies are mostly derived from those formulated for warm-blooded animals. However, differences in the dietary mineral requirements of fish and warm-blooded animals have become more and more apparent; it is, therefore, necessary to study much more extensively the role of each mineral element in fish nutrition—just as previous nutritionists studied individual vitamin requirements to establish the test diets for fish. It is considered that the improvement of mineral mixture supplements for diets will benefit not only researchers, but also those in the commercial fish feed industry.

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Résultats Expérimentaux sur *Penaeus japonicus*: Spécificité des Besoins Nutritionnels (Protéines et Acides Gras)

Aquacop

Résumé

Cette étude avait pour objet de préciser l'étendue de réponse de trois aliments de type commercial pour crevettes pénéides en retenant comme base d'interpretation la teneur en protéines et en acides gras polyinsaturés. Les tests de croissance étaient réalisés sur une seule espece, *P. japonicus*.

En 30 jours, les crevettes d'un poids moyen initial d'un gramme environ eurent un taux de croissance de 180% et un taux de survie supérieur à 90% avec l'aliment contenant 60% de protéines. Les deux autres aliments n'entraînèrent pas une croissance acceptable pour cette espèce alors qu'ils donnent des performances analogues pour d'autres espèces.

Les analyses immédiates et les analyses des lipides en chromatographie gazeuse effectuées sur les trois aliments et sur les crevettes en fin d'élevage, permettent d'apporter des explications aux différences observées: différence dans le niveau de protéines d'une part et différence dans les acides gras polyinsaturés (20:5 w3 et 22:6 w3 notamment) d'autre part. A teneur en protéines egale, l'aliment ayant la valeur de peroxydation des graisses la plus élevée donne la plus faible réponse.

Une spécificité des besoins en protéines et en acides gras des crevettes pénéides apparaît donc nettement et le choix d'un aliment commercial devra se faire en fonction de l'espèce que l'on souhaite élever.

Experimental results on *Penaeus japonicus*: specificity in nutritional requirements (proteins and fatty acids)

Abstract

The purpose of this study was to determine the range of response to three commercial penaeid prawn diets, considering their levels of proteins and polyunsaturated fatty acids. Growth tests were made on one species, *P. japonicus*.

In 30 days, 1 g average weight prawns gave a weight increase of 180% and a survival rate of 90% with a diet containing 60% protein. The other diets did not give any acceptable growth for *P. japonicus* but with other species the growth promotion was very good.

Proximate analysis and gas chromatography determination made on the three diets and on prawns at the end of the rearing period allow us to explain the growth tests: difference in protein level and difference in fatty acid composition (20:5 w3 and 22:6 w3) are of main interest. With the same protein level a diet with a high peroxydized value produced the poorest response.

There is a specificity in nutritional requirements and the choice in a commercial diet should be on the basis of the species chosen

Resultados experimentales con *Penaeus japonicus*: especificidad de las necesidades alimentarias (proteínas y ácidos grasos)

Extracto

El propósito de este estudio fue el de determinar el rango de respuesta de tres dietas comerciales para camarones peneidos tomando como base el nivel de proteínas y de ácidos grasos polinosaturados. Se realizaron ensayos de crecimiento sobre una sola especie, *P japonicus*.

En 30 días los camarones de un peso inicial promedio de 1 g tuvieron un aumento de 180% y una supervivencia de 90% con una dieta de 60% de proteínas. Las otras dietas no produjeron un crecimiento satisfactorio para el *P. japonicus*, pero con otras especies el crecimiento fue bueno

Los análisis proximales y los análisis con cromatografía de gases realizados sobre las tres dietas y sobre los camarones, al fin del periodo de crecimiento, nos permitieron explicar esos ensayos: diferencia en el nivel de proteína y diferencia en la composición de ácidos grasos polinosaturados (20:5 w3 y 22:6 w3) son de interés singular. Con el mismo nivel de proteína una dieta que tiene un valor de peroxidación de grasa alto exhibe la repuesta más débil.

Hay especificidad en los requerimientos alimenticios, y la seleccion de una dieta comercial debe depender de la especie seleccionada.

1 Introduction

La technique d'élevage en intensif des crevettes pénéides nécessite la mise au point d'aliments composés performants. Les travaux récents sur les besoins nutritionnels des pénéides font état de niveaux de protéines différents suivant les espèces; c'est ainsi que les aliments développés pour *P. japonicus* sont à 60% (Kanazawa, 1970; Shigueno, 1968), pour *P. vannamei* et *P. stylirostris* de 25 á 30%, pour *P. aztecus* 40% (Venkataramiah *et al.* 1975) et pour *P. setiferus* 30% (Andrews *et al.* 1972). D'autres travaux

(Kanazawa, 1975) soulignent l'importance de la composition en acides gras. Actuellement, plusieurs aliments sont commercialisés dont l'aliment type Shigueno 3·00 (60% de protéines) et l'aliment Ralston Purina à 20–30% de protéines. D'autres part, dans le cadre des recherches entreprises au Centre Océanologique du Pacifique sur la faisabilité de l'élevage de crevettes pénéides en Polynésie, un aliment expérimental (30% de protéines) a été développé pour *P. merguiensis* et *P. vannamei*.

Le but de cette expérience est d'étudier la croissance obtenue avec ces trois aliments sur une même espèce (*P. japonicus*) en retenant comme base d'interprétation leur teneur en protéines, la composition en acides gras ainsi que les performances de croissance obtenues sur d'autres espèces.

2 Matériel et méthodes

Cette expérience a porté sur les crevettes juvéniles de *P. japonicus* pesant entre 0,2 et 1,5 g et provenant d'une ferme pilote de la région de Kagoshima. Les animaux sont répartis au hasard dans des aquariums en verre de 30 litres équipés d'un double fond et d'un 'air lift'. L'eau de mer est renouvelée constamment à raison de 250 ml par minute environ. La salinité est de 35 pour mille, la température de 25,5°C et le pH 8,2; l'oxygène dissous est à saturation en raison de l''air lift'. L'expérience dure 30 jours. La nourriture est distribuée le soir à raison de 15% de la biomasse totale de départ; elle est ajustée suivant les restes. Chaque jour, le nombre de morts, l'excédent de nourriture et la quantité de fèces sont notés. Douze animaux sont placés dans chacun des bacs, le poids moyen de départ est de 1,0 g et les trois aliments (3·00, MR 30 et 45.1.1.0) sont testés en duplicata. L'aliment 3·00 développé pour *P. japonicus* se présente sous forme de vermicelles de 2 mm de diamètre ainsi que l'aliment 45.1.1.0 mis au point pour *P. merguiensis* et *P. vannamei*. Quant à l'aliment MR 30, il se présente sous forme de pastilles.

Les analyses de protéines, lipides, humidité résiduelle et valeur de peroxydation des graisses ont été effectuées sur ces aliments. D'autre part, la détermination des acides gras a été réalisée par chromatographie en phase gazeuse sur appareil GC—4B FF avec une colonne de succinate polymérisé de diethylène glycol à une température de four de 210°C (Kanazawa *et al*, 1975). Elle concerne les trois aliments, la farine de crevette, ingrédient du 45.1.1.0, et les animaux placés sur régime 3·00.

3 Résultats

Aucun effet bac n'a été observé.

L'aliment 3·00 à 60% de protéines donne 180% d'accroissement en 30 jours à partir d'animaux de 1,0 g de poids moyen et son efficacité est de 0,60. Par extrapolation, la biomasse totale obtenue est de 169 g/m^2. Les deux autres aliments à 30% de protéines donnent des croissances beaucoup plus faibles (Tableau I). La consommation quotidienne de l'aliment 3·00 est de 10% de la biomasse totale de départ des animaux; celle du 45.1.1.0 de 15% et celle du MR 30 de 8%. La survie est très bonne pour le 3·00 et le 45.1.1.0 mais légèrement inférieure pour le MR 30.

Les crevettes nourries sur aliments 3.00 et 45.1.1.0 produisent des fèces longs et abondants, tandis qu'avec le MR 30 ils sont courts et plus rares.

TABLEAU I
PERFORMANCES DE CROISSANCE, SURVIE ET EFFICACITÉ DES ALIMENTS SUR L'ESPÈCE P. JAPONICUS APRÈS 30 JOURS D'ÉLEVAGE

	Taux de survie	*Taux de croissance*	*Efficacité de l'aliment*
3.00 performant pour *P. japonicus*	96	180	0,60
MR 30 performant pour *P. vannamei*	87	26	0,11
45.1.1.0 satisfaisant pour *P. aztecus* et *P. merguiensis*	96	12	0,03

TABLEAU II
ANALYSE DES ALIMENTS POUR CREVETTES UTILISÉS DANS LE TEST DE CROISSANCE SUR P. JAPONICUS

Aliment	*Protéines (N×6,25)*	*Lipides %*	*Humidité résiduelle*	*POV meq/kg lipides*
3.00	60	6,3	13,0	11
MR 30	30	9,7	6,0	14
45.1.1.0	32	6,0	4,4	28

Les analyses des aliments ont été effectuées après l'expérience (Tableau II). On notera une valeur de peroxydation (POV) très élevée pour le 45.1.1.0.

La composition en acides gras des aliments présente des différences importantes. L'aliment 3.00 contient moins

TABLEAU III
COMPOSITION EN % D'ACIDES GRAS DES ALIMENTS POUR CREVETTES, DE LA FARINE DE CREVETTES AMÉRICAINE ET DE *P. japonicus* APRÈS 30 JOURS D'ÉLEVAGE

Acides gras	*Aliment MR 30*	*Aliment 3.00 (japonais)*	*Aliment 45.1.1.0*	*Farine de crevettes*[1]	*P. japonicus nourries sur aliment japonais*[1]
14·0	1,0	3,8	0,2	0,05	1,4
14:1w5		0,2	0,1	1,2	
15:0		0,7	0,2	0,1	0,7
16:0	14,1	22,0	0,1	5,1	14,0
16:1w7	1,8	17,4	0,7	0,6	12,1
16:1w9					
16·4w1		1,3		24,8	
16:4w1					
17:0	0,4	1,5	0,1	0,7	0,2
18:0	5,3	4,8	32,9	9,9	4,1
18:1w9	23,9	14,3	5,6	1,9	10,5
18:1w7				3,5	
18:2w6	44,8	11,8	0,9	2,3	1,6
18:2w4		1,2	0,2	0,8	
18:3w6		0,9	8,5		0,8
18:3w3	5,7	6,1	24,1	10,4	0,5
20:0				20,45	
20:1w9				2,3	0,4
20:1w15					
20:2w6	0,3	0,2	16,8	0,8	0,9
20:3w9					
20:4w6	0,5	1,7	1,1	5,5	
20:3w3					
18:4w3	0,2			0,5	0,7
22:0			2,9		1,1
22:1w9					0,1
20:3w3					4,8
22:1w9		2,7	2,0		1,8
20:5w3	1,5	4,0		1,2	25,6
22:4w6	0,2	0,7			1,1
24:0		0,2	1,0		
24:1w9		0,4	1,2	0,5	2,4
22:5w6		0,5			0,1
22:5w3			0,1		1,0
22:6w3	0,2	3,6		2,8	16,2
Total PUFA	55,2	29,3	43,0	21,4	52,8
Total w3	7,8	14,5	24,7	16,2	48,8
Total w6	45,4	14,8	18,3	5,2	4,0

[1] Teneur en lipides totaux: farine de crevettes 6,97%; *P. japonicus* nourries sur aliment japonais 1,32‰

d'acides gras polyinsaturés que le MR 30 et le 45.1.1.0 mais les niveaux de 20:5w3 et 22:6w3 sont plus élevés (Tableau III). L'acide linolénique (18:2w6) entre pour 44,8% des graisses du MR 30, l'acide linolénique (18:3w3) est en quantité plus grande dans le 45.1.1.0 que dans les deux autres. La farine de crevette US utilisée dans le 45.1.1.0 contient une faible proportion d'acides gras saturés (18:0) et la série w3 est bien représentée.

Après les tests de croissance, les crevettes nourries sur aliment 3.00 contiennent 1,3% de lipides totaux, les acides gras polyinsaturés essentiels sont abondants, 25,6% et 16,2% pour le 20:5w3 et le 22:6w3 respectivement. Par ailleurs, les crevettes ont une pigmentation prononcée et des antennes longues alors qu'elles sont pâles et leurs antennes sont coupées quand elles sont nourries sur MR 30 et 45.1.1.0.

4 Discussion

Le niveau de consommation des crevettes est inférieur à 10% pendant les 10 premiers jours d'expérience sur aliment 3.00. Ensuite, comme si une adaptation progressive des enzymes se produisait, la consommation devient excellente à 10% de la biomasse jusqu'à la fin.

L'accroissement en poids des *P. japonicus* nourries sur aliment à 60% est excellent. Ce résultat confirme ceux de Kanazawa (1970) et Deshimaru (1972) sur la même espèce. Les deux autres aliments qui donnent des performances analogues de croissance sur *P. vannamei* aboutissent sur *P. japonicus* à un très faible accroissement en poids, montrant ainsi qu'ils ne couvrent pas les besoins nutritionnels de cette espèce. Ainsi la spécificité des besoins en protéines apparaît clairement et un aliment mis au point pour une espèce dite primitive comme *P. vannamei* et *P. stylirostris* ne saurait convenir à toutes les autres (Kurata, 1975, communication personnelle). L'inverse peut d'ailleurs ne pas être vrai en ce sens qu'un aliment efficient pour *P. japonicus* peut fort bien convenir pour une espèce moins évoluée comme *P. merguiensis*. Certains travaux montrent en outre que des crevettes *P. aztecus* grandissent peu avec des aliments supérieurs à 40% de protéines (Venkataramiah *et al*, 1975). La classification de Kurata sur le monde écologique pourrait s'apparenter en certains points avec les besoins nutritionnels des crevettes pénéides. Il est possible que les besoins en protéines soient en rapport avec le degré d'évolution des différentes espèces. Kurata (1975, communication personnelle) place, en effet, sur des critères écologiques, *P. vannamei* parmi les espèces primitives alors que *P. japonicus* serait parmi les plus évoluées.

La plus faible performance obtenue sur *P. japonicus* par le 45.1.1.0, par rapport au MR 30 alors que les teneurs en protéines sont les mêmes et que le spectre d'acides aminés est semblable, peut s'expliquer par la composition en acides gras. A l'analyse, le 45.1.1.0 révèle en effet un minimum d'acides gras polyinsaturés (20:5w3 et 22:6w3) qui sont essentiels à *P. japonicus* (Kanazawa, 1975). Il possède par contre beaucoup d'acides gras saturés (18:0) et la valeur de peroxydation des graisses est le double de celle du MR 30 en raison de l'incorporation de farine de poisson de qualité moyenne dans la formule. Ces graisses saturées peuvent être toxiques pour les animaux. Il apparaît donc particulièrement important, lors de l'élaboration d'un aliment, de tenir compte non seulement du niveau de protéines et de l'équilibre du spectre d'acides aminés apportés par les ingrédients, mais encore des acides gras qui sont apportés en mélange. Il est à noter que les bons résultats de croissance obtenus sur *P. vannamei* avec le 45.1.1.0 laissent supposer là encore une spécificité des acides gras. Les acides gras (20:5w3 et 22:6w3) absents de la ration paraissent moins essentiels pour cette espèce.

5 Conclusion

Cette expérience a donc permis de comparer trois aliments élaborés pour des espèces de pénéides différentes, en regard du taux de croissance d'une seule espèce, *P. japonicus*. Elle confirme que cette espèce semble avoir des besoins nutritionnels importants qui ne sont satifaits que par un aliment riche en protéines (60%) et en acides gras polyinsaturés. Ces besoins ne sont plus du tout les mêmes quand il s'agit d'autres espèces comme par exemple *P. vannamei*. Ces quelques considérations ne doivent pas être perdues de vue lors du choix d'une espèce et d'un aliment pour des opérations de production commerciale.

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The Effect of Protein Levels and Sources on Growth of *Penaeus aztecus*

Z. P. Zein-Eldin and J. Corliss

Abstract

Extruded feeds comprising a soy flour-rice bran base were fed to laboratory-reared juvenile shrimp, *Penaeus aztecus*. Measured protein levels ranged from approximately 24 to 63% in increments of approximately 10%. Best growth was obtained with a feed containing 51·5% protein, while growth decreased at the highest protein level. Essentially no growth occurred amongst animals fed at the three lowest protein levels.

Simultaneous tests of animals fed three other diets varying in composition from those above suggested that protein level alone was not the factor involved in growth stimulation. Two feeds varying only 1% in protein content differed considerably in growth stimulation, while a third feed with almost 25% less protein was about as efficient. Analysis of amino acid composition of the feeds did not provide an explanation as to the differences in growth response.

Apparently, factors other than protein concentration or quality, which have not yet been identified, are important in the growth of penaeids.

Influence des niveaux protéiques et de l'origine des protéines sur la croissance de *Penaeus aztecus*

Résumé

Des aliments extrudés à base de farine de soja et de son de riz ont été administrés à des juvéniles de *Penaeus aztecus* élevés en laboratoire. Les niveaux protéiques mesurés s'échelonnaient de 24 à 63% environ, par

échelons de quelque 10%. Un aliment contenant 51·5% de protéines a donné la meilleure croissance, cette dernière diminuant à un niveau protéique plus élevé. La croissance a été pratiquement nulle parmi les crustacés auxquels on avait administré des aliments aux trois niveaux protéiques inférieurs.

Des tests simultanés portant sur des crustacés auxquels on a administré trois autres régimes alimentaires dont la composition était différente de ceux mentionnés précédemment permettent de penser que le niveau protéique n'est pas le seul facteur qui intervienne dans la stimulation de la croissance. C'est ainsi que deux aliments dont la teneur protéique ne différait que de 1% ont provoqué une stimulation de croissance très différente, alors qu'un troisième aliment contenant près de 25% de protéines en moins a été à peu près aussi efficace. L'analyse de la composition des aliments en acides amines n'a pas permis d'expliquer à quoi sont imputables ces reactions de croissance.

Apparemment, d'autres facteurs que la concentration ou la qualité protéique, qui n'ont pas encore été identifies, jouent un rôle important dans la croissance des peneides

Efectos del contenido de proteínas de los piensos y del origen de las mismas en el crecimiento de *Penaeus aztecus*

Extracto

Se alimentó a formas juveniles de camaron, *Penaeus aztecus*, criadas en laboratorio con piensos extruidos a base de harina de soja y salvado de arroz. El contenido de proteinas de los piensos varió entre un 24 y un 63%, aproximadamente, con incrementos de aproximadamente 10% Los mejores crecimientos se obtuvieron con piensos con un 51,5% de proteínas, mientras el crecimiento disminuyo con el contenido máximo de proteínas. En los animales a los que se suministraron piensos con los tres niveles más bajos de proteínas no se registró esencialmente ningun crecimiento.

Los ensayos realizados simultáneamente con animales alimentados con otras raciones de composicion distinta de las indicadas sugieren que el contenido de proteinas no es el unico factor que influye en el crecimiento Dos piensos con una diferencia de contenido de proteínas de sólo 1% arrojaron resultados considerablemente diversos, mientras un tercer pienso con casi un 25% menos de proteinas resulto casi igualmente eficaz. El análisis de la composicion en aminoácidos de los piensos no permitio explicar las diferencias de crecimiento

Parece ser, pues, que para el crecimiento de los peneidos son importantes otros factores diversos de la concentración o calidad de las proteinas, pero hasta la fecha no ha sido posible determinarlos

1 Introduction

Of major importance in the economic cultivation of any animal is the food requirement for protein. The economically valuable penaeid shrimp species have been studied by several groups to determine requirements for this parameter. Results have, however, been varied. For this reason, we have attempted to evaluate protein requirements in laboratory-reared *Penaeus aztecus* using a series of diets of similar composition, but varying in protein quantity.

2 Methods

All *Penaeus aztecus* used in this study were hatchery-reared, either at the Galveston Laboratory of the National Marine Fisheries Service or at Dow Chemical Company in Freeport, Texas, following procedures and feeding regimens described by Mock and Murphy (1971). Following development to postlarvae, animals were maintained on a diet of live naupliar brine shrimp until the young were approximately 45 mm total length and approximately 0·6 g in weight. Ten animals were then randomly assigned to glass aquaria of 60 l capacity with undergravel filters, sterilized substrates, and filtered sea water (Zein-Eldin and Meyers, 1973), and held in constant temperature rooms maintained at 28 ± 1°C. Salinity in all aquaria was 25 ppt. Two randomly assigned groups of shrimp (20 individuals in all) were given each feed. Individual animals were measured to the nearest 0·5 mm (rostrum-telson length), blotted and weighed to the nearest 0·1 mg and identified individually by clipping uropods. Individuals were weighed, measured, and reclipped every 2 to 3 weeks. Mean initial weight was 0·705 ± 0·193 g with a range of 0·4389-1·3331 g. Mean final weight (after 106 days) of survivors (all feeds combined) was 5·21 ± 1·33 g with a range of 2·56-9·28 g.

Animals were fed weighed amounts of extruded feeds twice daily with amounts adjusted at each feeding depending upon the presence or absence of feed in the aquarium. Excess feed was removed, but no correction for dry weight of uneaten feed was made in calculation of approximate conversion rates.

Because the design of isocaloric diets requires the modification in amount and kind of several ingredients (notably the addition of fats), the decision was made to vary only two components without regard to the caloric values of the resulting feeds. Experimental feeds in this experiment differ from the control customarily used at the Galveston Laboratory (Zein-Eldin and Meyers, 1973). None of these feeds included components other than those used in the control, and these in different ratios. All used menhaden extractives as attractant and were bound with alginate (Meyers and Zein-Eldin, 1972; Meyers, Butler and Hastings, 1972). The principal protein sources were of vegetable origin: rice bran (defatted) and soy flour. The ingredients of the experimental feeds are listed in Table I as well as the analytical values for protein percentage which ranged from approximately 24 to 63% in 10% intervals.

3 Results

As is apparent from Fig. 1, there was no significant increase in mean weight among shrimp fed at the three lowest protein levels over a period of 47 days. This contrasts with an approximate tripling of weight at the two higher protein levels during this time. Although moulting did occur in the

TABLE I
PERCENTAGE COMPOSITION OF EXPERIMENTAL FEEDS

Ingredient[a]	*Control 5-5/70B*	*1*	*2*	*3*	*4*	*5*
Menhaden meal	8	5	5	5	5	5
Shrimp meal (sun dried)	31·5	3	3	3	3	3
Fish solubles	2	2	2	2	2	2
Lecithin	1	1	1	1	1	1
Vitamin mix	2	2	2	2	2	2
Kelgin	2·5	2·5	2·5	2·5	2·5	2·5
Sodium hexametaphosphate	1	1	1	1	1	1
Rice bran (defatted)	49[b]	83·5	64·5	45	25	5·5
α-soy flour	3	0	19	38·5	58·5	78
Protein content (by analysis)	29·6	23·9	33·8	43·4	51·5	62·9

[a] Ingredient sources described in Meyers and Zein-Eldin (1973)
[b] Non-defatted rice bran used in this feed

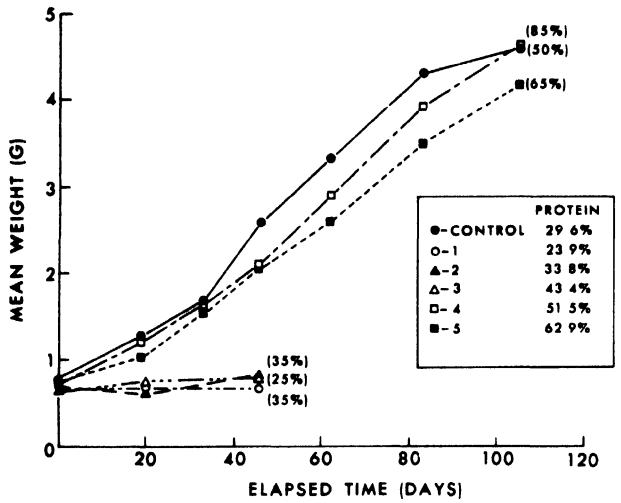


Fig 1. Mean weight of *Penaeus aztecus* given diets containing various levels of protein. Feed composition as in *Table 1.* Figures in parenthesis indicate survival

tanks fed at the lower protein levels, it was less frequent and instances of negative growth (decrease in weight) were recorded.

The protein content of the feed affected not only the final mean size of the shrimp but also the ability of the individuals to withstand the stress of handling during measurement. Only 70% of the animals fed diets of 43·4% protein or less (diets 1, 2, and 3) survived the 19 days prior to the first measuring period (Table II) and an additional 20% of these animals died within 24 hours following the 19 day measurement. The decreased survival among these shrimp is reflected in an absolute decrease in biomass of animals fed at the lower protein levels (Fig. 2). It must also be noted that animals at the lower protein levels consumed only about one fifth the feed eaten by animals at the higher protein levels (Table III).

On the basis of survival, resistance to stress (handling), moulting frequency, recorded increase in individual size and biomass, it would appear that the protein content of a feed satisfactory for *P. aztecus* must be greater than 43·4%. The range of protein content would also appear to be critical, because growth was less with a feed of 62·9% protein than with one of 51·5% protein (Fig. 2; Table II).

Simultaneously, however, three additional feeds were tested: a modification of our standard feed containing non-defatted rice bran, and two commercial feeds obtained from

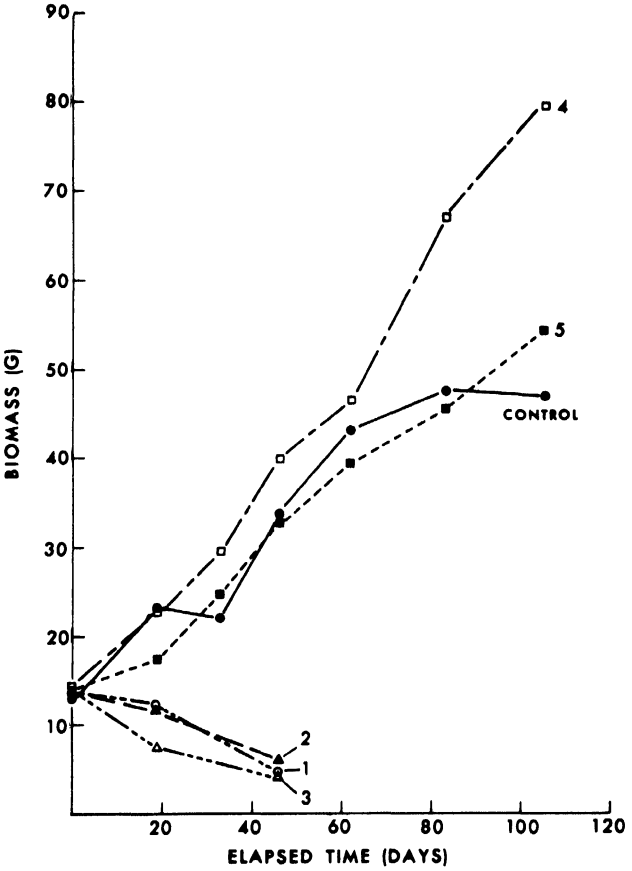


Fig 2. Combined biomass of *Penaeus aztecus* fed various levels of protein. Symbols as in *Fig 1.*

TABLE II

INCREASE IN MEAN WEIGHT OF *Penaeus aztecus* JUVENILES FED RATIONS OF VARYING PROTEIN LEVELS. MEAN WEIGHT IN G ± STANDARD DEVIATIONS TEST AQUARIA LISTED SEPARATELY. NUMBER OF ANIMALS MEASURED IN PARENTHESES

Feed	Elapsed Time (Days)						
	0	19	33	46	62	83	105
1 (a)	.729 ± .221 (10)	.696 ± .186 (8)		.689 ± .134 (4)			
(b)	.677 ± .173 (10)	.679 ± .127 (10)		.659 ± (3)			
Combined	.700 ± .195 (20)	.687 ± .151 (18)		.676 ± .103 (7)			
2 (a)	.702 ± .259 (10)	.664 ± .250 (9)		.809 ± (3)			
(b)	.707 ± .241 (10)	.611 ± .085 (9)		.906 ± .296 (4)			
Combined	.704 ± .244 (20)	.637 ± .183 (18)		.864 ± .267 (7)			
3 (a)	.693 ± .172 (10)	.720 ± .114 (4)		.813 (2)			
(b)	.656 ± .166 (10)	.758 ± .153 (6)		.814 (3)			
Combined	.674 ± .166 (20)	.742 ± .133 (10)		.814 ± .082 (5)			
4 (a)	.744 ± .062 (10)	1.237 ± .475 (9)	1.708 ± .481 (9)	2.281 ± .488 (9)	2.986 ± .646 (9)	3.947 ± .798 (9)	4.595 ± .975 (9)
(b)	.719 ± .198 (10)	1.178 ± .187 (9)	1.591 ± .250 (9)	2.131 ± .347 (9)	2.820 ± .477 (7)	3.954 ± .642 (8)	4.798 ± .697 (8)
Combined	.732 ± .220 (20)	1.207 ± .352 (18)	1.650 ± .418 (18)	2.206 ± .418 (18)	2.914 ± .566 (16)	3.950 ± .706 (17)	4.691 ± .867 (17)
5 (a)	.730 ± .169 (10)	1.001 ± .263 (9)	1.408 ± .246 (7)	2.050 ± .182 (8)	2.571 ± .344 (7)	3.478 ± .490 (6)	4.129 ± .716 (6)
(b)	.679 ± .178 (10)	1.064 ± .267 (8)	1.700 ± .264 (8)	2.055 ± .262 (8)	2.665 ± .407 (8)	3.550 ± .887 (7)	4.243 ± 1.135 (7)
Combined	.705 ± .171 (20)	1.033 ± .247 (17)	1.562 ± .288 (15)	2.053 ± .218 (16)	2.621 ± .368 (15)	3.516 ± .704 (13)	4.190 ± .928 (13)
5-5/70B (a)	.727 ± .279 (10)	1.282 ± .318 (8)	1.480 ± .290 (6)	2.507 ± .384 (5)	3.480 ± .293 (5)	4.157 ± .552 (5)	4.679 ± .698 (5)
(b)	.694 ± .183 (10)	1.301 ± .296 (10)	1.869 ± .274 (7)	2.651 ± .308 (8)	3.220 ± .475 (8)	4.463 ± .709 (6)	4.614 ± 1.116 (5)
Combined	.710 ± .227 (20)	1.293 ± .297 (18)	1.690 ± .337 (13)	2.596 ± .331 (13)	3.320 ± .421 (13)	4.324 ± .631 (11)	4.668 ± .877 (10)
F-1 (a)	.749 ± .168 (10)	1.297 ± .331 (10)	2.118 ± .551 (9)	2.892 ± .469 (9)	3.516 ± .502 (8)	4.901 ± .558 (8)	5.424 ± .560 (8)
(b)	.682 ± .115 (10)	1.210 ± .243 (10)	1.869 ± .350 (9)	2.753 ± .319 (10)	3.308 ± .340 (10)	4.225 ± .412 (10)	5.022 ± .405 (9)
Combined	.716 ± .145 (20)	1.254 ± .279 (20)	1.994 ± .466 (18)	2.819 ± .392 (19)	3.400 ± .420 (18)	4.525 ± .581 (18)	5.211 ± .512 (17)
K-25 (a)	.690 ± .168 (10)	1.926 ± .170 (8)	2.812 ± .332 (9)	3.751 ± .377 (9)	4.512 ± .449 (7)	5.763 ± .256 (6)	6.802 ± .531 (7)
(b)	.707 ± .220 (10)	1.908 ± .303 (8)	2.717 ± .358 (8)	3.704 ± .407 (8)	4.884 ± .694 (8)	6.062 ± .904 (8)	7.523 ± 1.418 (7)
Combined	.699 ± .191 (20)	1.917 ± .237 (16)	2.767 ± .337 (17)	3.729 ± .400 (17)	4.710 ± .604 (15)	5.934 ± .699 (14)	7.163 ± 1.095 (14)

Japan, K-25 and F-1. Growth with feed K-25[1] was greater than with any other feed tested, whether expressed as increase in biomass or increase in mean weight of individuals (Fig. 3; Table II). Growth with feed F-1 (which has a protein content only 1–2% less than that of K-25) was significantly less and animals fed this diet did not greatly exceed in mean weight those fed the control which had only about 30% protein. Detailed amino acid analyses of these three feeds did not provide a ready explanation of the observed differences in growth rate (Table IV).

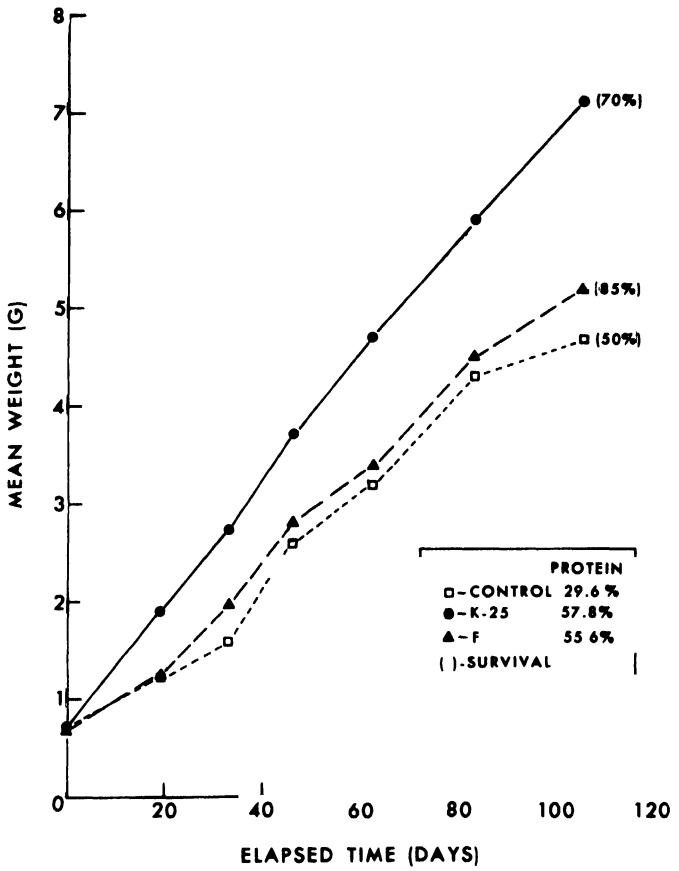


Fig 3. Mean weight of *Penaeus aztecus* fed two commercial feeds of greater than 50% protein, compared with standard feed (control) 5-5/70B. Figures in parenthesis indicate survival

4 Discussion

This study emphasizes the need for further experimentation concerning both the requirements and the utilization of protein by penaeids. Previously published studies have suggested a variety of protein optima. *Penaeus setiferus* is said to have a protein optimum of 28–32% (Andrews, Sick and Baptist, 1972), *Penaeus aztecus* (Venkataramiah, Lakshmi and Gunter, 1975) and *P. monodon* (Lee, 1971) optima of about 40%, while *P. japonicus* requires more than 60% protein (based upon descriptions of diets tested by Deshimaru and Shigueno, 1972) and at least 50% purified protein (Deshimaru and Kuroki, 1975). Although the results of present studies are in general agreement with the studies on *P. aztecus* and *P. monodon*, they strongly suggest that factors other than protein content, or even protein quality, may be as important as the content of protein in feeds for penaeids, particularly those in intensive culture systems.

Thus, the presence of 20% more protein than in the standard feed did not ensure a consistent increase in growth rate in *P. aztecus*. Almost equivalent growth rates were obtained with diets varying in total protein between 30% and 53·5% protein, while diets differing only 1% brought about significantly different increases both in weight and biomass.

Decreased growth at the highest protein level was noted in *P. setiferus* fed diets of 40% and 52% protein (Andrews, Sick and Baptist, 1972) and has also been described in *P.*

[1] Obtained from Koywa Hakko Koygo Limited

TABLE IV

AMINO ACID COMPOSITION OF EXPERIMENTAL FEEDS EXPRESSED AS PERCENTAGE OF TOTAL SAMPLE WEIGHT. MEAN OF DUPLICATE SAMPLES

	5-5/70B	*F-1*	*K-25*
Lysine	1·676	3·678	4·240
Histidine	0·726	1·011	1·203
Arginine	2·207	2·932	4·097
Taurine	[a]	0 464	0·223
Aspartic acid	3·653	6·442	7·310
Threonine	1·052	2·166	2·576
Serine	1·197	2·379	2·464
Glutamic acid	4·083	8·259	8·613
Proline	1·262	2·693	2·431
Glycine	1·792	3·919	3·035
Alanine	1·612	3·674	3·337
Valine	1·280	2·860	2·779
Methionine	0·518	1·356	1·336
Isoleucine	1·003	2·372	2·545
Leucine	1·895	4·865	4·469
Tyrosine	1·470	1·930	1·978
Phenylalanine	1·208	2·300	2·425
Ammonia	0·728	0·910	0·956
Total protein	29·51	55·58	57·93

[a] Not determined

TABLE III

CONVERSION RATIOS OF *Penaeus aztecus* JUVENILES FED DIETS OF VARYING PROTEIN CONTENT AND COMPOSITION

Feed	*Elapsed time*									
	46 days					*105 days*				
	(*1*) *Feed supplied* (*g*)	(*2*) *Protein supplied* (*g*)	(*3*) *Biomass change*[a] (*g*)	(*4*) *Conversion ratio*[b]	(*5*) *Cols. 2 ÷ 3*	(*1*) *Feed supplied* (*g*)	(*2*) *Protein supplied* (*g*)	(*3*) *Biomass change*[a] (*g*)	(*4*) *Conversion ratio*[b]	(*5*) *Cols. 2 ÷ 3*
1	30·5	7·3	−9·3	−3	−1	—	—	—	—	—
2	38·4	13·0	−8·0	−4	−2	—	—	—	—	—
3	28·9	12·5	−9·4	−3	−1	—	—	—	—	—
4	161·3	83·0	25·07	6·4	3·3	487·1	250·9	65·11	7·5	3·9
5	85·0	53·5	18·75	4·5	2·9	252·6	159·0	40·37	6·3	3·9
Control	192·7	57·0	19·55	9·9	2·9	430·3	116·0	32·48	13·2	3·6
F-1	162·6	93·5	39·24	4·2	2·4	499·8	287·0	74·30	6·7	3·9
K-25	172·3	100·0	49·41	3·5	2·0	438·5	257·0	86·34	5·7	3·0

[a] Absolute change in biomass, not corrected for mortalities
[b] Conversion ratio = feed supplied/biomass change; not corrected for uneaten feed

aztecus juveniles by Venkataramiah, Lakshmi and Gunter (1975) and in *P. monodon* by Lee (1971). This raises a question concerning the high protein feeds described by various Japanese workers culturing *P. japonicus*: are there such significant differences in protein requirements among penaeid species? If so, culture would be best restricted to those species which can be grown adequately using feeds of lower protein content and of lower cost (*eg*, high quantities of cereal or grain protein rather than animal protein).

It must also be mentioned that utilizable protein may be lower than that suggested from analytical results, particularly at the lowest protein levels described, since Lee (1970) has indicated that *P. monodon* uses rice bran about 10–20% less efficiently than other vegetable proteins. Should this be true of *P. aztecus*, effective protein levels might be considerably less in our control feed (5–5/70B) than indicated by the analytical results.

Conversion ratios were calculated using the absolute biomass change. Although many authors have used a ratio which corrects for mortality (Kitabayashi, 1971), it is felt that the use of actual biomass change provides a more realistic evaluation of the economic potential of a given feed under actual culture conditions. Animals in these experiments were fed *ad libitum*, and under some conditions of physiological stress (*eg*, immediately prior to or following moult) they ate less than expected. The weight of uneaten feed was not subtracted from the total amount of feed supplied so that conversion ratios as given in Table IV may be considered maximal. After either 46 or 105 days, the control feed was least efficient (highest conversion ratio) among feeds yielding a positive change in biomass. If, however, percentage of protein is considered, the control was second in rank in the long-term experiment. Thus, evaluation of the potential of these feeds in economic terms requires knowledge of growth rates, biomass changes (independent of survival) and the cost of feed per protein unit.

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Replacement of Fish Meal in Trout Feeds by Other Feedstuffs

J. Gropp, H. Koops, K. Tiews and H. Beck

Abstract

Experiments were conducted at both fresh- and brackishwater sites to determine the extent to which fish meal in diets for rainbow trout (*Salmo gairdneri*) can be replaced by other feed components without decreasing the quality of the feed.

Eight different feed components were tested in five experiments using a standard trout diet of 70% fish meal as the control. The trout, held in net cages, and fed at a rate of 2% of the body weight per day were raised from a weight of 50–80 g up to 250–300 g.

The fish protein of the standard diet could be replaced entirely by a mixture of poultry by-product meal and hydrolyzed feather meal on an isonitrogenous basis if essential amino acid deficiencies were corrected. Half of the dietary fish meal protein could be replaced by methione-supplemented alkane yeast and a soy protein concentrate (HAYPRO) respectively. Soybean oil meal gave less favourable results. One quarter of the dietary fish meal protein could be replaced by isonitrogenous amounts of corn gluten meal or a mixture of meat and bone meal and blood meal.

These partial replacements could be made even if the remaining dietary protein came from poultry by-product meal and feather meal.

Remplacement de la farine de poisson par d'autres produits dans l'alimentation des truites

Résumé

Des expériences ont été conduites tant en eau douce qu'en eau saumâtre pour déterminer la mesure dans laquelle la farine de poisson peut être remplacée par d'autres aliments dans l'alimentation de la truite arc-en-ciel (*Salmo gairdneri*) sans nuire à la qualité de la nourriture.

Huit constituants alimentaires différents ont été testés au cours de cinq expériences utilisant comme témoin une ration normalisée contenant 70% de farine de poisson. Les truites, gardées dans des cages constituées de filets, et alimentées au taux de 2% du poids du corps par jour, sont passées d'un poids de 50–80 g à 250–300 g.

Les protéines de poisson figurant dans l'alimentation normale ont pu être remplacées entièrement par un mélange de farine constituée de sous-produits avicoles et de farine de plumes hydrolysée sur une base isoazotée, à condition de corriger les carences essentielles en amino acides. La moitié des protéines fournies par la farine de poisson ont pu être remplacées par une farine d'alkane enrichie au methione ou par un concentré de protéines de soja (HAYPRO). Une alimentation à base defarine de tourteaux de soja a donné des résultats moins satisfaisants. Le quart des protéines fournies par la farine de poisson a pu être remplacé par des quantités de farine de gluten de maïs iso-azoté ou un mélange de farine de viande et d'os et de farine de sang

Ces remplacements partiels ont pu être réalisés même si le reste des protéines de l'alimentation a été fournie par de la farine constituée de sous-produits avicoles et par de la farine de plumes.

Sustitución de la harina de pescado por otros nutrientes en los piensos pára truchas

Extracto

Se han realizado experimentos en aguas dulces y salobres para determinar en qué medida es posible sustituir la harina de pescado en las raciones alimenticias de la trucha arco iris (*Salmo gairdneri*) por otros elementos nutrientes sin que los piensos pierdan en calidad.

Se ensayaron ocho elementos diversos en cinco experimentos, utilizando como testigo una ración normalizada para truchas con un 70% de harina de pescado Se criaron las truchas en jaulas, alimentándolas con una ración diaria equivalente al 2% de su peso corporal, desde 50–80 g hasta 250–300 g de peso.

Durante los ensayos resultó posible sustituir totalmente las proteínas de pescado de la ración normalizada por una mezcla de harina hecha de subproductos avícolas y harina hidrolizada de plumas, sobre una base isonitrogenada, siempre que las deficiencias esenciales de aminoácidos fuesen corregidas. Resultó igualmente posible sustituir la mitad de las proteínas de harina de pescado presentes en la ración con levaduras alcánicas suplementadas con metionina o un concentrado de proteínas de soja (HAYPRO). La harina de torta de soja dió resultados menos favorables. Pudo sustituirse además un cuarto de las proteínas de harina de pescado de la ración con cantidades de isonitrogenado de harina de gluten de maíz o de una mezcla de harina de carne y huesos y harina de sangre.

Estas sustituciones parciales resultaron posibles aun cuando el resto de las proteínas de la ración procedieran de harina hecha de subproductos avícolas y harina de plumas.

1 Introduction

In 1970, a co-operative research programme was started by the Institut für Küsten- und Binnenfischerei and the Institut für Physiologie, Physiologische Chemie und Ernährungsphysiologie of the University of Munich to develop optimal pellet feeds for intensive farming of rainbow trout (*Salmo gairdneri*) in cages (Gropp *et al*, 1974; Koops, 1970; Koops *et al*, 1974 and 1975; Mertz, 1972; Tiews *et al*, 1972 and 1973; Tiews, Gropp and Koops, 1975). One of the major objectives of this programme has been to develop a feed of high and constant quality (standard diet) as well as to evaluate different protein sources. Economic aspects have also been considered in selecting feed components for evaluation. This paper summarizes the latest results of these studies[1].

Considering the soy experiments, differentiation must be made between the soy protein *per se* and the soy protein source. There is no doubt that soy protein is a valuable protein source for trout, but soybean oil meal does not seem to be, at least not at the 50% replacement level. Although HAYPRO is well utilized by trout, up to 50% of dietary protein, the poorer results obtained with soybean oil meal are probably correlated with its carbohydrate fraction or its content of enzyme inhibitors and haemagglutinin or with both.

2 Methodology

Two experimental stations were available, one at the German Electron Synchrotron (DESY) in Hamburg-Bahrenfeld and one in Eckernförde on the western coast of the Baltic[2]. In Hamburg-Bahrenfeld up to 12 net cages measuring $2 \times 2 \times 2$ m could be held in a concrete pond of the DESY about 1 000 m^2 in area and 5 m in depth. The pond is fed with heated cooling water from a ground-water source at a rate of about 12 l/s. The water temperature fluctuates between 8°C in winter and some 20°C during the summer.

In Eckernförde, at the end of the Bight of Eckernförde, up to 16 cages were available having dimensions of $4 \times 1{\cdot}8 \times 3{\cdot}5$ m (1 m above and 2·5 m below the water surface). Each cage has a volume of about 14 m^3. The cages are installed under a navy bridge and are well protected against stormy weather. The depth of the water where the net cages are located is 6–12 m. The salinity ranges between 13 and 20 ppt and the water temperature between 4° and 24°C from April to October.

For each experimental run, 150–200 fish were placed in each cage. Rainbow trout used in the experiments were usually stocked at an average weight of 50–80 g and reared to commercial sizes of 250–300 g. At the DESY, one experiment normally lasted up to 120 days; at Eckernförde, approximately 160–180 days. Control measurements were made every 3–4 weeks. Fish were fed with experimental diets at a daily rate of about 2% of body weight twice daily for six days a week. The quantity was adjusted daily according to the feeding activity of the fish and as near to *ad libitum* intake as possible. The average quantity of feed per unit weight of fish was the same in each experiment.

The group that grew the slowest, either as a result of poor feed conversion or from a diet which was not well accepted, determined the feeding level for the whole experiment. This means that normally the feed conversion data of an experiment also reflect the growth rate. The quantity of feed used per cage was adjusted every day as necessary to offset the effect of fish losses. Each experimental group consisted of two or three replicates (cages).

Calculations of results were made with a WANG 700 B computer. All experimental diets were compared to a standard diet with a defined protein and energy level and high protein quality (Table I).

Seventy percent fish meal (about 60% crude protein, 7% ether extract, 4% calcium and 2·2% phosphorus) was used as the predominant protein source.

TABLE I
COMPOSITION OF THE STANDARD DIET USED TO COMPARE WITH OTHER TEST DIETS

	%
Fish meal	70·0
Fish oil	8·0
Sodium-propionate	0·3
Vitamin-premix[1]	2·0
Wheat meal (gelatinized)	19·7
	100·0[2]

[1] Vitamin-premix contains in 20 g: 40 000 IU vitamin A, 1 000 IU vitamin D_3, 100 mg α–tocopherol-acetate, 5 mg menadione-bisulphite, 500 mg ascorbic acid, 15 mg thiamine, 30 mg riboflavine, 15 mg pyridoxine, 0·07 mg cobalamine, 2 mg folic acid, 1 5 mg biotine, 1 g choline, 50 mg Ca-pantothenate, 150 mg nicotinic acid, trace elements (as sulphates), 40 mg Mn, 10 mg Zn, 5 mg Cu, 0 05 mg I (as KI)

[2] Typical crude nutrient analysis 46% crude protein, 13% ether extract, 13% ash, 3% Ca and 1 6% P

3 Substitutes for fish meal

3.1 *Poultry by-products*

A series of experiments was carried out using a protein-equivalent mixture of poultry by-product meal and hydrolyzed feather meal in place of fish meal. At the beginning of these experiments, the crude protein levels of poultry by-product meal and feather meal were determined as 50% and 83% respectively, so that a mixture of these components with a ratio of 5·7:4·3 gave the same protein concentration as fish meal (64%). During the course of the experiments, the protein level of poultry by-product meal was increased up to 60%. Because the ratio of the two components was not changed, the poultry by-product diets were slightly higher in their protein content than the control diet.

Feed components used in the first series of three experiments are shown in Table II and the results of these experiments with poultry by-products are summarized in Table III. From these data it can be concluded that three quarters of the fish meal protein of the standard ration (equivalent to 52·5% fish meal in the 46% crude protein standard) can be replaced by 30% poultry by-product meal and 22·5% hydrolyzed feather meal. By this procedure, the high performance of trout fed with the standard diet is not altered. This conclusion is at least partly confirmed by the results of a fourth experiment (details not shown). No remarkable differences were obtained between a 50% poultry by-product protein ration (145 g gain, 1·42 g feed/g gain in 52 feeding days) and a 75% ration (149 g gain, 1·38 g feed/g gain). Mortality rate was not influenced by the different feeds. Even a 100% replacement of fish meal by poultry by-product meal and feather meal gives only

[1] The experiments discussed are part of a research programme for the development of optimal trout feeds financed by the Federal Ministry for Research and Technology, Bonn

[2] The sites of the specific experiments shown in Tables II–IX are designated as follows: D—DESY in Hamburg-Bahrenfeld; E—Eckernförde

slightly poorer results if supplemented with the deficient amino acids lysine, methionine and tryptophan (Table III). The result led to a further experiment. It is well known that in the case of a protein having an amino acid deficiency, the amino acid requirement can be compensated for, not only by supplementing missing amino acids, but at least within certain limits by providing a higher quantity of the same deficient protein.

Therefore, in experiment E XII/75, rations with a higher feather meal content were tested. Feather meal was incorporated into the diet in exchange for gelatinized wheat starch (see Table IV). This consideration was supported by the economical fact that feather meal is essentially cheaper than precooked wheat starch.

There is no evidence in the results (Table V) that any remarkable difference exists between the control diet of this experiment and a ration consisting only of poultry by-products supplemented with lysine and methionine, fat and vitamins. However, these results need additional confirmation.

3.2 *Other animal protein sources*

Meat and bone meal, alone and in combination (protein equivalent to fish meal) with blood meal and an alkane-grown yeast, were tested.

An isonitrogenous mixture of meat and bone meal and blood meal cannot be compared with either fish meal or poultry by-products. The successful 25% replacement of fish meal protein by meat and bone meal and a mixture of meat, bone and blood meal respectively obviously depends on the other dietary protein sources. The higher protein values of fish meal in comparison to poultry by-products may be the reason that the 25% replacement by meat, bone and blood meal gives better results than the 25% replacement by meat and bone meal in a diet without any fish meal (Table VI).

The experimental data, summarized in Tables VII and VIII, for incorporating yeast products in the diet show good utilization by trout of alkane yeast (Toprina, product of BP) within the tested range. The slight improvement (with 25% dietary protein from yeast) resembles the effect observed after replacing 25% fish meal protein by poultry by-products. Arginine supplementation of the 50% yeast protein diet does not appear to give different results (Tables VII and VIII). However, arginine is an essential amino acid for salmon (Mertz, 1972).

3.3 *Soy protein*

In comparison to the standard diet, complete replacement of fish meal by an isonitrogenous mixture of soybean oil

TABLE II

COMPOSITION AND CRUDE NUTRIENT ANALYSIS (PERCENT) OF DIETS USED IN EXPERIMENTS D VII/73, E IX/74 AND D X/74 (REPLACEMENT OF FISH MEAL BY POULTRY BY-PRODUCTS)

	Poultry by-product meal protein as percentage of fish meal protein					
	0	*25*	*50*	*75*	*100*	*100 + AA*[1]
Sodium-propionate	0·3	0 3	0·3	0·3	0·3	0 3
Redfish oil	8·0	8 0	8·0	8·0	8 0	8 0
Vitamin-premix[1]	2·0	2·0	2·0	2·0	2·0	2 0
Wheat (gelatinized)	19·7	19 7	19·7	19 7	19·7	17·376
Fish meal	70·0	52·5	35·0	17·5	—	—
Poultry by-product meal	—	10·0	20·0	30·0	40·0	40·0
Feather meal (hydrolyzed)	—	7 5	15·0	22·5	30·0	30·0
Amino acids[2]	—	—	—	—	—	2·324
Crude protein	46·1	47·2	50·2	52·6	48·1	48·9
Ether extract	12·2	13·3	11 5	11·5	12·3	12·8
Water	9·6	8·8	8·3	7·3	6·9	6·8
Ash	12·7	10·8	8·9	6·7	4·7	4·8
Calcium	3·02	2·52	2·15	1·67	1·25	1·34
Phosphorus	1·55	1·38	1·23	0·98	0·80	0·84

[1] See Table I
[2] Amino acids: 1·7% l-lysine HCl, 0·48% dl-methionine, 0·144% dl-tryptophan

TABLE III

WEIGHT GAIN AND FEED EFFICIENCY OF RAINBOW TROUT FOR EXPERIMENTS: D VII/73 (125 EXPERIMENTAL DAYS, 96 FEEDING DAYS, 11·1°C MEAN WATER TEMPERATURE); E IX/74 (88 EXPERIMENTAL DAYS, 68 FEEDING DAYS, 13·8°C MEAN WATER TEMPERATURE); AND D X/74 (102 EXPERIMENTAL DAYS, 69 FEEDING DAYS, 11·5°C MEAN WATER TEMPERATURE) TO TEST DIETARY REPLACEMENT OF FISH MEAL BY POULTRY BY-PRODUCTS

Experiment	*Standard diet (70% fish meal)*	*Poultry by-product meal protein as percentage of fish meal protein*				
		25	*50*	*75*	*100*	*100 + AA*[1]
gain (g)						
D VII/73	201	214	215	—	—	—
E IX/74	133	142	127	124	117	126
D X/74	172	—	—	189	—	—
Average (relative figures)	(100)	(107)	(102)	(102)		
g feed/g gain						
D VII/73	0·99	0·93	0·94	—	—	—
E IX/74	1·33	1·24	1·41	1·40	1·52	1·37
D X/74	1·40	—	—	1·36	—	—
Average (relative figures)	(100)	(94)	(101)	(101)		

[1] Amino-acid supplement: 1·7% l-lysine HCl, 0·48% dl-methionine, 0·144% dl-tryptophan

TABLE IV

COMPOSITION AND CRUDE NUTRIENT ANALYSIS (PERCENT) OF DIETS USED IN EXPERIMENT E XII/75 (REPLACEMENT OF FISH MEAL AND CARBOHYDRATE BY POULTRY BY-PRODUCTS)

Percent of dietary fish meal protein replaced	*50*	*75*	*75*	*100*
Percent of dietary carbohydrate replaced	*0*	*0*	*100*	*100*
Calcium-propionate	0·3	0·3	0·3	0·3
Redfish oil	7·0	7·0	7·0	7·0
Vitamin-premix[1]	0·6	0·6	0·6	0·6
Wheat (gelatinized)	22·1	22·1	—	—
Fish meal	35·0	17·5	—	—
Poultry by-product meal	20·0	30·0	30·0	40·0
Feather meal (hydrolyzed)	15·0	22·5	62·1	50·87
Amino acids[2]	—	—	—	1·23
Crude protein	51·5	52·7	65·6	67·8
Ether extract	14·5	17·8	20·9	21·0
Water	7·5	7·0	6·7	6·0
Ash	9·2	8·1	8·0	6·4
Calcium	2 35	2·25	2 17	2·14
Phosphorus	1·51	1·22	1·16	1·10

[1] See Table I
[2] 1 06% l-lysine HCl, 0 17% dl-methionine

TABLE V

WEIGHT GAIN AND FEED EFFICIENCY OF RAINBOW TROUT FOR EXPERIMENT E XII/75 (64 EXPERIMENTAL DAYS, 52 FEEDING DAYS, 18·8°C MEAN WATER TEMPERATURE) TO TEST DIETARY REPLACEMENT OF FISH MEAL AND CARBOHYDRATE BY POULTRY BY-PRODUCTS

Percent of dietary fish meal protein replaced	*50*	*75*	*75*	*100*
Percent of dietary carbohydrate replaced	*0*	*0*	*100*	*100*
gain (g)	145	149	147	144
(relative figures)	(100)	(103)	(101)	(99)
g feed/g gain	1·37	1·38	1·40	1·41
(relative figures)	(100)	(101)	(102)	(103)

TABLE VI

WEIGHT GAIN AND FEED EFFICIENCY OF RAINBOW TROUT FOR EXPERIMENTS D X/74 AND E IX/74 TO TEST DIETARY REPLACEMENT OF FISH MEAL BY POULTRY BY-PRODUCTS, MEAT AND BONE MEAL, AND MEAT AND BONE MEAL PLUS BLOOD MEAL

	Percent replacement of fish meal protein				
Poultry by-products					
Mean and bone meal	75	75	—	—	50
Meat and bone meal, blood meal	—	25	—	75	— 25
	—	—	—		
	Experiment				
	D X/74		E IX/74		
gain (g)	189	157	133	108	130
(relative figures)	(100)	(83)	(100)	(81)	(98)
g feed/g gain	1·36	1·64	1·33	1·59	1·34
(relative figures)	(100)	(121)	(100)	(120)	(101)

meal and isolated soy protein (Purina RP 100) gave unsatisfactory results (Koops *et al*, 1975). Growth rate in the soy group was depressed by 68%; feed efficiency by 231%. Even supplementation of the soy diet by the amino acids methionine, lysine and glycine did not influence these unfavourable results.

Nevertheless HAYPRO, a soy protein concentrate with about 60% crude protein was tested. HAYPRO has been used with success in milk-replacement formulae for calves (Gropp, 1972), whereas soybean oil meal was unsatisfactory.

Experiments D VIII/74 and D X/74 provided similar

TABLE VII

COMPOSITION AND CRUDE NUTRIENT ANALYSIS (PERCENT) OF DIETS USED IN EXPERIMENT E XII/75 (REPLACEMENT OF FISH MEAL BY ALKANE YEAST)

Poultry by-products	50	50	50	50
Alkane grown yeasts	—	25	50	50 + AA[1]
Calcium-propionate	0·3	0·3	0·3	0·3
Redfish oil	7·0	7·0	7·0	7·0
Vitamin-premix[2]	0·6	0·6	0·6	0·6
Wheat (gelatinized)	22·1	20·74	19·38	18·83
Fish meal	35·0	17·5	—	—
Poultry by-product meal	20·0	20·0	20·0	20·0
Feather meal (hydrolyzed)	15·0	15·0	15·0	15·0
Alkane yeast[3]	—	18·70	37·40	37·40
Amino acids	—	0·16[5]	0·32[4]	0·87[1]
Crude protein	51·5	49·8	50·6	51·4
Ether extract	14·5	13·7	11·9	13·1
Water	7·5	7·2	7·2	6·6
Ash	9·5	7·5	5·3	5·9
Calcium	2·35	2·2	0·99	1·11
Phosphorus	1·51	1·34	1·09	1·18

[1] 0·32% dl-methionine, 0·55% l-arginine HCl
[2] See Table I
[3] Product of BP, United Kingdom
[4] 0·32% dl-methionine
[5] 0 16% dl-methionine

TABLE VIII

WEIGHT GAIN AND FEED EFFICIENCY OF RAINBOW TROUT FOR EXPERIMENT E XII/75 (104 EXPERIMENTAL DAYS, 83 FEEDING DAYS, 17·4°C MEAN WATER TEMPERATURE) TO TEST DIETARY REPLACEMENT OF FISH MEAL BY ALKANE YEAST

	Percent replacement of fish meal protein			
Poultry by-products	50	50	50	50
Alkane yeast	—	25	50	50 + AA
gain (g)	210	218	216	221
(relative figures)	(100)	(104)	(103)	(105)
g feed/g gain	1 38	1·34	1·36	1·32
(relative figures)	(100)	(97)	(98)	(95)

results (Tables IX and X) in that, independent from the main (75%) protein source, HAYPRO can be incorporated in trout feeds at a level of 25% of the dietary protein. In both experiments there was no difference in the corresponding control groups. This means that fish meal can be completely replaced on a protein basis by 75% poultry by-products and 25% HAYPRO. However, a slight tendency for decrease in growth rate and feed efficiency was shown if 50% of the dietary protein were replaced by HAYPRO, and 75% replacement by HAYPRO led to a significant depression of overall performance.

These data were encouraging enough, despite the first results with soybean oil meal and isolated soy protein (Purina) (Koops *et al*, 1975), to compare HAYPRO with soybean oil meal on a 50% replacement level. In the HAYPRO group, 229 g gain and 1·65 g feed/g gain were measured while only 215 g gain and 1·72 g feed/g were obtained in the soybean oil meal group. Consequently there must be a basic difference in the feeding value of the soy protein concentrate HAYPRO and normal soybean oil meal.

3.4 *Corn gluten meal*

Corn gluten meal is a high protein feed component (about 60% crude protein) but has inferior protein quality (low lysine and tryptophan levels).

Rainbow trout tolerate and utilize corn gluten meal amounting to 25% of the dietary protein (Table XI). It is worth mentioning that, in comparison with the control group, equal or even slightly better results were obtained

with a diet containing 50% of its protein as vegetable protein and 50% as poultry by-product protein.

4 Discussion

Poultry by-product meal and hydrolyzed feather meal are suitable feed components which can more or less replace all the fish meal (70%) of a standard trout diet.

Fish meal-free trout diets can contain as much as 30% feather meal as a protein source. This is a surprising finding since, as far as is known, not more than 5–10% feather meal can be included in a complete feed for other monogastric animals (pigs, poultry) without harmful effects (*eg*, growth depression).

The high protein requirement of trout (about 45% of the ration) is not connected with equally high amino acid requirements as could be expected according to the amino acid pattern of fish body protein. Trout protein contains about 8% lysine (Tiews *et al*, 1973). The lysine and tryptophan requirement data given by Mertz (1972) are 5·0% and 0·5% of dietary protein respectively.

Our diet, with 50% of the dietary protein coming from fish meal and 50% from poultry by-product meal and feather meal, contains 5·0% lysine and 0·8% tryptophan (calculated levels). Another reason for favouring the poultry by-product mixture is its arginine level (6·7% of protein). The arginine requirement of trout is suggested as 6·0% of dietary protein (Mertz, 1972). Fish meal contains only 5·9% arginine and 7·5–8·0% lysine.

This may also explain why good results were obtained with alkane yeast (4·8% arginine) in combination with poultry by-products independent from an arginine supplement.

At the 75% replacement level of fish meal protein by poultry by-products, there is a shortage of lysine (4·3% of protein) in comparison to the requirement data. However, good results with the poultry by-products, HAYPRO and corn gluten meal diet (3·8% lysine) in experiment D XI/75 (Table XI) may support the suggestion that the lysine requirement of trout is possibly lower than estimated so far.

On a 46–50% dietary protein basis, the original amino acid level (mainly lysine and methionine) of poultry by-products is not sufficient to replace fish meal successfully. As was demonstrated, these differences can be compensated by adding the deficient amino acids.

The diet consisting only of poultry by-product meal and feather meal (plus fat and vitamins) (see Table IV) provides a higher amino acid supply than does the ration with 75% dietary protein coming from poultry by-products. All amino acids of this diet which are not used to cover the essential amino acid requirement of trout serve as an energy source. The energy value of a highly digestible protein, not correlated with the protein value, is always higher than the corresponding carbohydrates. Consequently, it depends only on the actual price situation whether protein (of poor quality) is used as an energy source instead of carbohydrates.

TABLE IX

COMPOSITION AND CRUDE NUTRIENT ANALYSIS (PERCENT) OF DIETS USED IN EXPERIMENTS D VIII/74, D X/74 AND D XI/75 (REPLACEMENT OF FISH MEAL BY HAYPRO SOY PROTEIN CONCENTRATE)

	Percent replacement of dietary fish meal protein						
HAYPRO	—	25	—	25	—	50	75
Poultry by-products	—	—	—	75	50	50	—
Sodium- (or calcium-) propionate	0·3	0·3	0·3	0·3	0·3	0·3	0·3
Redfish oil	8·0	8·0	8·0	8·0	7·0	7·0	7·0
Vitamin-premix[1]	2·0	2·0	2·0	2·0	0·6	0·6	0·6
Wheat (gelatinized)	19·7	18·2	19·7	18·2	22·1	19·1	17·6
Fish meal	70·0	52·5	70·0	—	35·0	—	17·5
Poultry by-product meal	—	—	—	30·0	20·0	20·0	—
Feather meal (hydrolyzed)	-	-	—	22·5	15·0	15·0	
HAYPRO[2]	—	19·0		19·0	—	38·0[3]	57·0[3]
Crude protein	45·2	45·4	46·7	52·5	46·1	49·3	47·1
Ether extract	13·2	13·1	16·5	16·7	14·4	12·5	14·3
Water	n.d.	n.d.	9·4	6·9	6·5	6·3	6·5
Ash	12·2	10·7	13·5	4·7	10·9	5·5	7·6
Calcium	2·81	2·29	3·20	0·97	2·67	1·25	1·16
Phosphorus	1·53	1·35	1·81	0·68	1·47	0·81	0·92

[1] See Table I
[2] Supplemented with dl-methionine (1·2% of soy protein)
[3] Lysine equivalent to fish meal
n.d. = not determined

TABLE X

WEIGHT GAIN AND FEED EFFICIENCY OF RAINBOW TROUT FOR EXPERIMENTS: D VIII/74 (90 EXPERIMENTAL DAYS, 68 FEEDING DAYS, 15·8°C MEAN WATER TEMPERATURE); D X/74 (102 EXPERIMENTAL DAYS, 69 FEEDING DAYS, 11·5°C MEAN WATER TEMPERATURE); AND D XI/75 (140 EXPERIMENTAL DAYS, 91 FEEDING DAYS, 18·0°C MEAN WATER TEMPERATURE) TO TEST DIETARY REPLACEMENT OF FISH MEAL BY HAYPRO SOY PROTEIN CONCENTRATE

	Percent replacement of dietary fish meal protein						
HAYPRO	—	25	—	25	—	50	75
Poultry by-products	—	—	—	75	50	50	—
	Experiment						
	D VIII/74		D X/74		D XI/75		
gain(g)	177	180	172	174	236	229	205
(relative figures)	(100)	(101)	(100)	(102)	(100)	(97)	(87)
g feed/g gain	1·43	1·38	1·40	1·41	1·59	1·65	1·82
(relative figures)	(100)	(97)	(100)	(100)	(100)	(104)	(115)

TABLE XI

WEIGHT GAIN AND FEED EFFICIENCY OF RAINBOW TROUT FOR EXPERIMENT D XI/75 (140 EXPERIMENTAL DAYS, 91 FEEDING DAYS, AND 18·0°C MEAN WATER TEMPERATURE) TO TEST DIETARY REPLACEMENT OF FISH MEAL BY CORN GLUTEN MEAL

	Percent replacement of dietary fish meal protein		
Corn gluten meal	—	25	25
Poultry by-products	50	50	50
HAYPRO	—	—	25
gain (g)	236	249	246
(relative figures)	(100)	(106)	(104)
g feed/g gain	1 59	1·51	1·55
(relative figures)	(100)	(95)	(97)

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Evaluation of Squid Mantle Meal as a Protein Source in Penaeid Nutrition

J. L. Fenucci and Z. P. Zein-Eldin

Abstract

In studies aimed at finding cheaper, more efficient feeds for use in intensive culture of penaeids, squid mantle meal was used as a compo nent. Laboratory-reared juvenile *Penaeus aztecus* were fed experimental diets based upon a standard ration, 5–5/70B containing 49% rice bran. Rice bran was replaced by varying percentages of either α soy flour or squid mantle meal. Increase in mean weight, biomass and survival were more satisfactory with feeds containing 5% or 15% squid mantle meal than with feeds containing higher percentages (30% or 49%) of squid meal. Growth at the higher concentration (49%) of α-soy was also reduced. Regardless of protein source, both growth and survival were less when protein exceeded 60%.

Addition of squid meal in low percentages appears favourable to shrimp growth and may be economical in areas where squid can be obtained at low cost.

Evaluation de la farine de manteau d'encornet comme source de protéines pour la nutrition des pénéides

Résumé

Lors d'études destinées à trouver des aliments meilleur marché et plus efficaces pour l'élevage intensif des pénéides, on a utilisé comme composant des aliments la farine de manteau d'encornet. L'on a appliqué à des juvéniles de *Penaeus aztecus* élevés en laboratoire des régimes alimentaires bases sur une ration standard de 5–5/70B contenant 49% de son de riz. Le son de riz a été remplacé en pourcentages variables soit par de la farine de α-soja, soit par la farine de manteau d'encornet. L'accroissement du poids moyen, de la biomasse et du taux de survie était supérieur avec les aliments contenant de 5% ou 15% de farine de manteau d'encornet qu'avec ceux contenant des pourcentages plus élevés (30% ou 49%) de ce composant. La croissance a également diminué pour un taux de concentration plus élevé (49%) de la farine de α-soja. Quelle que soit l'origine des protéines, la croissance et le taux de survie étaient moindres lorsque leur taux de concentration excédait 60%.

L'adjonction de farine d'encornet en faibles pourcentages semble favoriser la croissance des crevettes et peut présenter un intérêt économique dans les régions où il est possible de se procurer des encornets à peu de frais.

Valor de la harina de manto de calamares como fuente de proteínas para la nutrición de peneidos

Extracto

En los estudios dirigidos a encontrar piensos más baratos y eficaces para el cultivo intensivo de peneidos se ha utilizado como componente, entre otras cosas, harina de manto de calamares. Se alimentó a formas juveniles de *Penaeus aztecus* criadas en laboratorio con raciones experimentales basadas en una ración uniforme 5–5/70B con un 49% de salvado de arroz. Se sustituyó el salvado de arroz, en diversos porcentajes, por harina de α-soja o harina de manto de calamar. El aumento del peso medio y de la biomasa y la supervivencia de los camarones resultaron más satisfactorios con piensos con un 5% ó 15% de harina de manto de calamares que con piensos con porcentajes mayores de dicha harina (30% ó 49%). Además con la concentración más elevada (49%) de α-soja el crecimiento resultó menor. Independientemente del origen de las proteínas, tanto el crecimiento como la supervivencia disminuyeron con un contenido de proteínas superior al 60%.

La adición de harina de calamar en pequeños porcentajes resulta favorable para el crecimiento de los camarones y puede resultar una solución económica en las zonas donde es posible conseguir calamares a bajo costo.

1 Introduction

One of the main problems in intensive shrimp culture is to find an inexpensive artificial diet which ensures the rapid growth of shrimp from juvenile to commercial size with good survival. To solve this problem diets have been tested for *Penaeus aztecus* based on diet FDSC 5–5/70B (Meyers and Zein-Eldin, 1973). Variations of this diet have been made by changing the quality and percentage of protein and by replacing rice bran with α-soy and squid meal.

2 Material and methods

Glass aquaria of 60 l capacity were prepared with under-gravel filters and filter beds consisting of oyster shell and sand (Zein-Eldin and Meyers, 1973). Natural sea water used in the experimentation was passed through a 5 μ filter and then through a quartz ultraviolet sterilizer. Aquaria were placed in controlled temperature rooms maintained at 27 ± 1°C. Both temperature and salinity varied somewhat during the course of the experiments. In experiment PSQ-1, recorded temperatures ranged between 28·6 and 31·6°C, and salinities between 21·5 and 24·8 ppt. In experiment PSQ-2, temperature ranged between 26·8 and 30·0°C and salinity between 21·4 and 23·6 ppt.

In experiment PSQ-1, ten hatchery-reared *Penaeus aztecus* were placed in each aquarium; the initial biomass per aquarium ranged from 4·875 to 6·142 g. In PSQ-2, 15 animals were placed in each aquarium; the initial biomass per aquarium ranged from 5·069 to 7·442 g. Two aquaria were used for each diet. Experimental animals were measured (rostrum-telson length) to the nearest 0·5 mm and weighed to the nearest mg approximately every two weeks. Animals were identified by cutting uropods to establish individual growth rates.

The shrimp were fed twice daily. The initial feeding level was approximately 5% of the biomass per day. Uneaten

feed was removed daily together with exuviae and any dead shrimp. The amount of feed was adjusted so that animals were provided with as much as they would eat, and was not held at a fixed percentage of biomass. The amount fed was recorded and feed efficiencies and conversion ratios were calculated using corrected weight as described by Kitabayashi *et al* (1971a).

Some of the feeds contained squid mantle meal as a component. This was prepared from fresh squid obtained from commercial fishermen. Viscera and pen were removed, the mantles were boiled for five minutes in water containing 5% sodium chloride, and the solids removed by filtration. Solids were dried in an oven at 80°C and ground to produce the meal. Mantles only were used in this series of experiments because of the variability in condition of the live animals.

2.1 *Feed composition*

Feeds were produced using a cold extrusion process with a high viscosity alginate as a binder (Meyers, Butler and Hastings, 1972). Diet composition is listed in Table I together with the protein percentages determined by analysis. Addition of components was made at the expense of rice bran, the component present in largest amount and found to be least digestible (Lee, 1971). In diets B and C soy protein was used in place of some of the rice bran. In diets D, E, F, and K varying percentages of squid mantle meal were substituted.

3 Results

3.1 *Experiment PSQ-1*

Diets were based upon the control diet containing 3% soy meal. Rice bran was replaced at two levels of both soy meal and squid meal; additional soy flour at 15% (total 18% soy) in diet B, and 49% (52% total soy) in diet C; 15% squid meal (F), and 49% squid meal (D).

Animals fed diet *F* (15% squid) increased in mean weight from 0·5 to 3·5 g (Table I, Fig. 1) while animals fed either diet *B* or the control feed (5–5/70B) reached about 2·4 g, and those fed *D* (49% squid) were only 2·0 g after 49 days. During the first 13 days of experimentation, shrimp growth with feed *D* was similar to that with feed *F*, but after this time growth on feed *D* decreased and deaths occurred. Animals fed diet *C* weighed only 1·163 g at the end of the experiment.

Initial combined biomass (for each diet in two aquaria) varied between 9·95 and 11·63 g, or 4·88–6·14 g per aquarium (21·95–27·30 g/m^2). Combined biomass increased more than 30 g for the groups fed diet *F* and for those fed the control (60 g/m^2), but the increase was less than 5 g for those given feeds *C* and *D* (Fig. 2). Best survival was observed among animals fed the control, while animals fed diet *D* (49% squid mantle meal) had the highest mortality rate. Survival was not always equal between replicates. For example, one of the groups fed diet *F* showed 90% survival, while only 30% of the animals survived in the other.

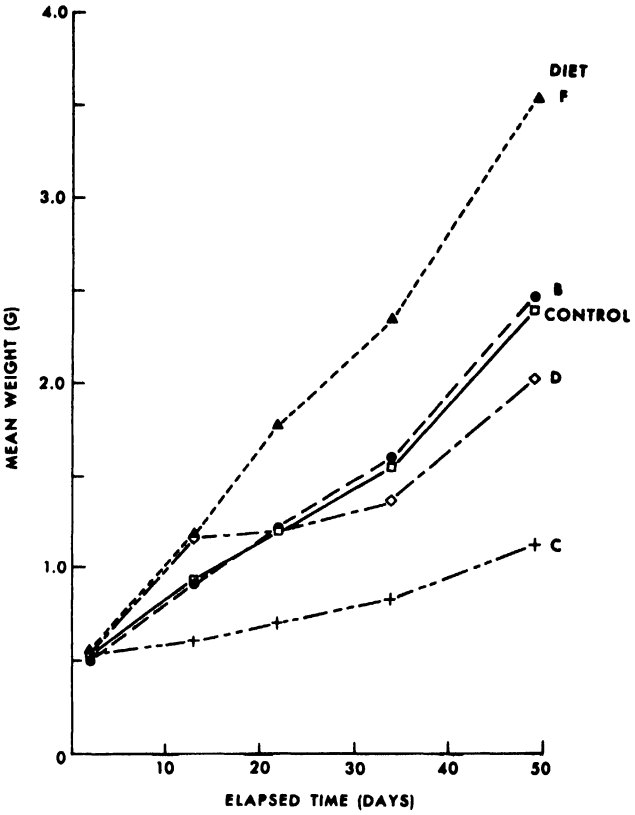


Fig 1. Experiment PSQ-1. Increase in mean weight of *Penaeus aztecus* juveniles fed diets containing soy and squid meal. Composition of experimental feeds as given in *Table I*

Feed efficiency varied between 22·2 and 30·9%, or conversion rates varied between 3·2 and 4·5 (Table II). The significance of these differences is doubtful.

3.2 *Experiment PSQ-2*

The results of the first experiment suggested that squid mantle meal at 15% level was superior, but that amounts as large as 49% were unsatisfactory; consequently, in this new series of experiments two additional levels of squid mantle meal were tested, 5% (*K*) and 30% (*E*). As a further comparison, two replicate tanks of shrimp were fed a commercially available feed obtained from Japan (K-25)[1],

[1] Obtained from Kyowa Hakko Kogyo Co. Ltd

TABLE I

FEED COMPONENTS (PERCENT) USED IN DIETS FOR EXPERIMENTS PSQ-1 AND PSQ-2. SOURCES OF INGREDIENTS OTHER THAN SQUID MEAL AS GIVEN IN ZEIN-ELDIN AND MEYERS (1973)

	Control (5–5/70B)	*B*	*C*	*D*	*E*	*F*	*K*
Menhaden	8·0	8·0	8·0	8·0	8·0	8·0	8·0
Shrimp meal	31·5	31·5	31·5	31·5	31·5	31·5	31·5
Rice bran	49·0	34·0	—	—	19·0	34·0	44·0
α-soy flour	3·0	18·0	52·0	3·0	3·0	3·0	3·0
Squid meal	—	—	—	49·0	30·0	15·0	5·0
Menhaden solubles	2·0	2·0	2·0	2·0	2·0	2·0	2·0
Lecithin	1·0	1·0	1·0	1·0	1·0	1·0	1·0
Alginate	2·5	2·5	2·5	2·5	2·5	2·5	2·5
Na hexametaphosphate	1·0	1·0	1·0	1·0	1·0	1·0	1·0
Vitamin mix	2·0	2·0	2·0	2·0	2·0	2·0	2·0
Protein percent by analyses	35·5	47·3	69·0	62·5–65·1	55·4	44·9	43·0

previously found to be the most successful in promoting growth of *P. aztecus* (Zein-Eldin and Corless, 1978).

The greatest increase in mean weight occurred among shrimp fed diet *F*, which gained from 0·44 to 4·10 g in 42 days (Table III). Good growth was also obtained with K-25 (3·14 g increase). Animals fed other test diets reached a final weight of 2·5–3·0 g (Table III and Fig. 3).

Total initial biomass (for each diet in two aquaria) ranged between 12·32 and 13·39 g (5·71 and 7·44 g per aquarium; 25·38–33·07 g/m^2). Final biomass was greatest among animals fed *K-25*; 64·91 g or an increase of 51·64 g in 42 days (Fig. 4). Final biomass was similar among the three feeds: *F* (15% squid), *K* (5% squid), and the control; with increases in biomass of 35·91 g for *F*, 34·97 g for *K*, and 31·45 g for the control. Diets higher in squid meal (*D* and *E*) produced much lower biomass increase, only 8·63 g among animals fed *D* (49% squid meal) and 16·0 g among animals fed *E* (30% squid meal).

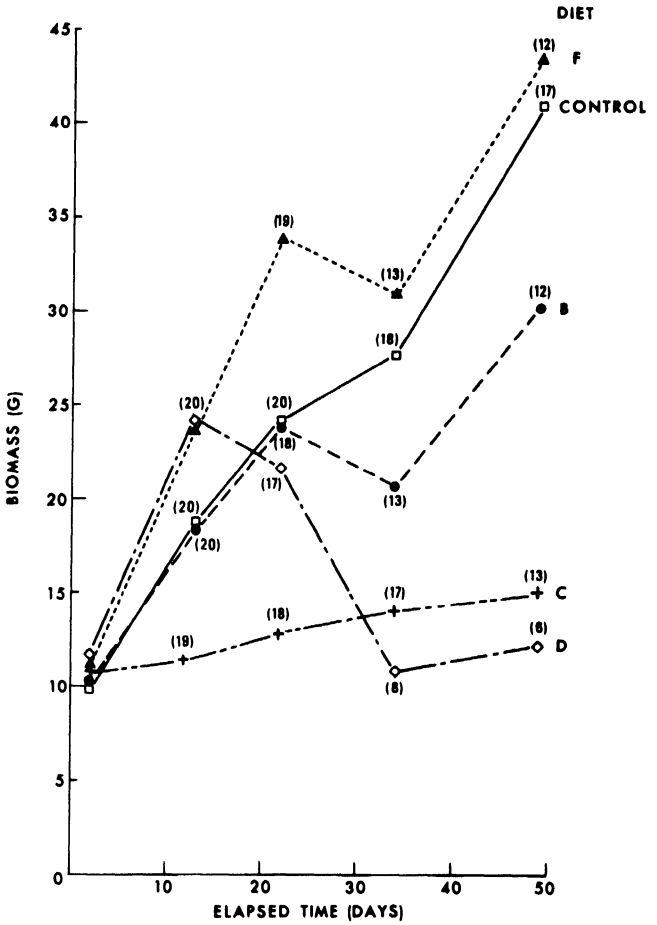


Fig 2. Experiment PSQ 1 Change in combined biomass of replicate tanks of juvenile *Penaeus aztecus* fed diets containing soy and squid meal. Numbers in parenthesis indicate survivors at each measurement period

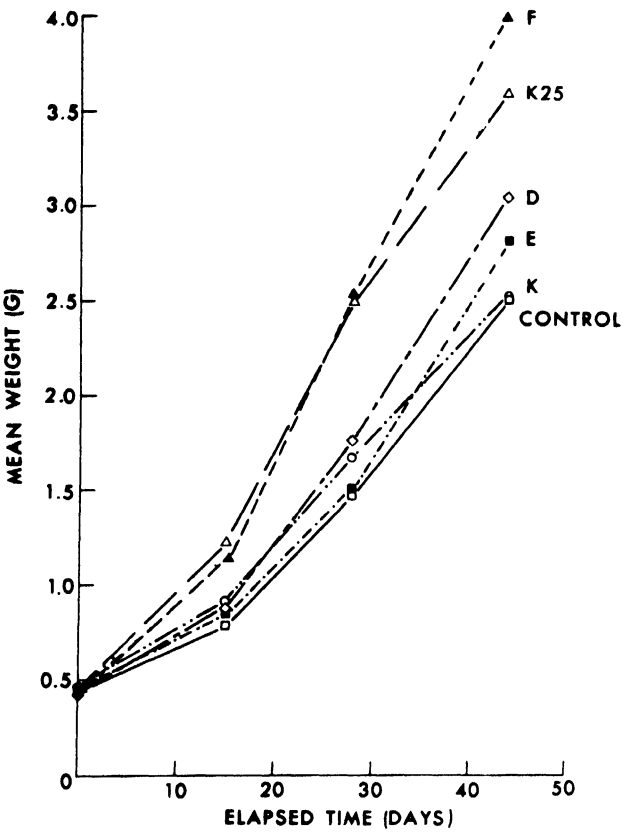


Fig 3. Experiment PSQ-2. Increase in mean weight of *Penaeus aztecus* fed diets containing various levels of squid mantle meal. Feed composition as given in *Table I*

TABLE II

EXPERIMENT PSQ 1. EFFECTS OF DIETS WITH TWO LEVELS OF SOY AND SQUID MEAL ON THE GROWTH, SURVIVAL AND CONVERSION RATE OF LABORATORY-REARED *Penaeus aztecus*—ELAPSED TIME: 49 DAYS

Diet	*Mean weight (g)*		*Biomass (g)*		*Survival* (%)	*Amount fed* (g)	*Feed efficiency* (%)	*Conversion rate*	*Protein ingested* (g)
	Initial	*Final*	*Initial*	*Final*					
B	0·52 ± 0·215	2·52 ± 0·716	10·41	30 30	60·0	103·6	30·9	3·2	49 0
C	0·53 ± 0·234	1·16 ± 0·345	10·75	15·12	65·0	40·3	25·6	3·9	28 0
D	0·55 ± 0·261	2·02 ± 0·786	11·63	12·17	28·5	71·6	24·2	4·1	45 0
F	0·55 ± 0·233	3·62 ± 1·039	11·04	43·54	60·0	168·2	22·2	4·5	76·0
Control	0·49 ± 0·224	2·42 ± 0·705	9·95	41·19	85·0	126·4	28·2	3 5	45·0

TABLE III

EXPERIMENT PSQ-2. EFFECTS OF DIETS WITH DIFFERENT LEVELS OF SQUID MEAL ON THE GROWTH, SURVIVAL AND CONVERSION RATES OF LABORATORY-REARED *Penaeus aztecus*—ELAPSED TIME: 42 DAYS

Diet	*Mean weight (g)*		*Biomass (g)*		*Survival* (%)	*Amount fed* (g)	*Feed efficiency* (%)	*Conversion rate*	*Protein ingested* (g)
	Initial	*Final*	*Initial*	*Final*					
D	0·42 ± 0·096	3·05 ± 1·075	12·78	21·40	30·0	181·7	28·1	3·5	118·3
E	0·41 ± 0·090	2·83 ± 1·412	12·32	28·32	33·3	188·3	25·7	3·9	104·3
F	0·44 ± 0·108	4·10 ± 0·668	13·26	49·16	40·0	190·3	40·3	2·4	85·4
K	0·44 ± 0·199	2·54 ± 1·015	13·39	48·36	63·3	174·3	29·5	3·4	74·9
K-25	0·44 ± 0·149	3·61 ± 0·540	13·27	64·91	60·0	187·5	40·5	2·5	108·6
Control	0·48 ± 0·135	2·53 ± 0·868	14·15	45·60	60·0	178·3	28·3	3·5	63·3

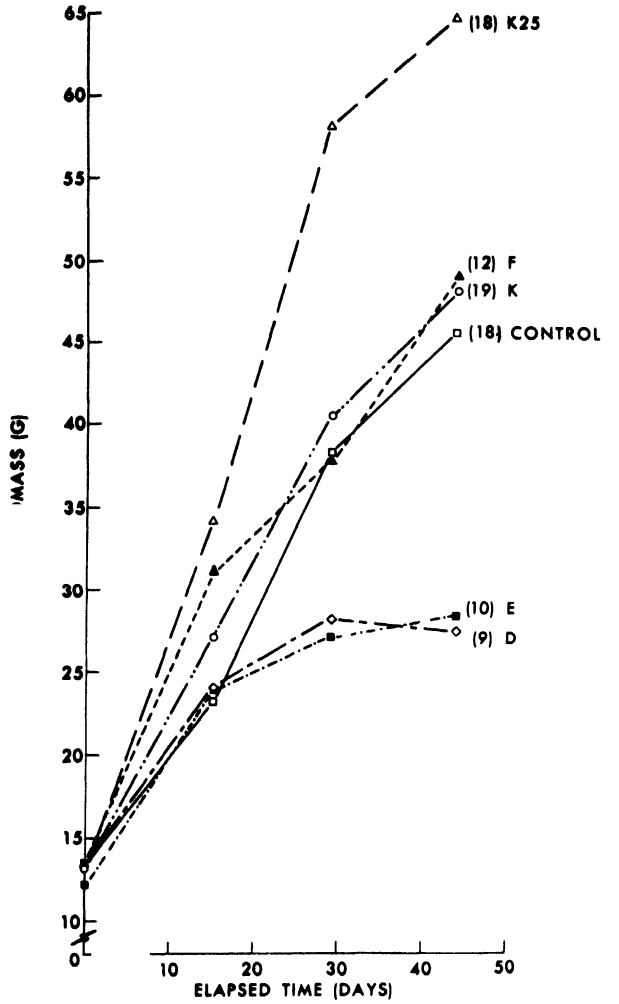


Fig 4. Experiment PSQ-2. Increase in combined biomass of *Penaeus aztecus* juveniles fed diets containing various percentages of squid meal. Numbers in parenthesis indicate survivors at termination of experiment

The increase in biomass is related to survival of the shrimp, with survival least in the aquaria fed *D* and *E*, and highest with *K* and *K-25*. As in the first experiment, survival between replicate tanks of animals fed *F* was not consistent, with nine animals surviving in one tank, but only three in the other.

The best efficiency, about 40%, was obtained with diets *K-25* and *F* (Table III). Others in the test were about 10–15% less, ranging from 25–29%.

Animals in PSQ-2 generally grew somewhat better than those in the earlier experiment, although the first experiment was seven days longer than the second. Conversely, survival was somewhat less in PSQ-2 than in PSQ-1; and in both experiments replicate tanks did not have similar survival. In both experiments, however, animals fed diet *D* (49% squid meal) began to die after about two weeks and in both series survival of these groups of animals was least, and survival of animals fed the control diet was either highest, or very nearly so.

4 Discussion

Diets with different percentages of soy flour, diet *C*, with 52% (49% more than the control), and diet *B*, 18% (15% more than the control) were used in the experiments. Good growth occurred only with the diet with the lesser amount of soy flour. Zein-Eldin and Corliss, however, reported growth comparable to that with the control when soy flour was present in percentages as great as 58%, and only slightly decreased growth with 78% soy flour. Sick and Andrews (1973) also used a feed with 58% soy meal which produced superior growth in *Penaeus duorarum*. Therefore, the inhibition of growth with diet *C* is likely to be a result of an excess of soy flour, or a consequent lack of methionine. It may be due to some synergistic relationship among the components. Texture of feeds containing large amounts of soy bean meal also varies from that of rice bran feeds, and may play an important role in feed acceptability. Significantly less feed was ingested by those animals given diet *C* (Table II).

These experiments utilized feeds with a limited range of protein contents (Table I). In both cases with high protein (diet *C* with 69% protein as fed, and diet *D* with 62·5–65·1% protein as fed), growth was less than on the diet using the same components but with lower protein content. This is in agreement with the studies of Zein-Eldin and Corliss (this volume) who suggested that the optimum percentage was greater than 43% but less than 65% in feeds with components including large amounts of soy flour. Studies of Venkataramiah, Lakshmi and Gunter (1975) also suggested that protein percentages greater than 50% resulted in decreased growth in *P. aztecus*.

Balazs, Ross and Brooks (1973) suggested that the best growth in *P. aztecus* and *P. japonicus* was obtained with more than 40% protein, and Deshimaru and Shigueno (1972) tested no diets for *P. japonicus* that had less than 60% protein. Others have reported decreased growth at high protein levels. Lee (1971) working with *P. monodon*, also reported a lower growth rate at 62% protein as compared to 46%, although growth increased with protein percentage in the range of 2–46%. Finally, Andrews, Sick and Baptist (1972) found the best growth with *P. setiferus* when feeding diets with protein between 28% and 32%, and decreasing growth between 40% and 52%.

It would thus appear that growth does not have a simple relationship to the percentage of protein but is related both to the quality of these proteins and to the relations among the other components of the diet.

It may also be worth considering whether various species have differing protein requirements based upon ability to use different amounts of vegetable material.

Squid has been used as a protein source by several authors (Subrahmanyam and Oppenheimer, 1969; Kitabayashi *et al*, 1971b; Deshimaru and Shigueno, 1972; Kittaka, 1975), both whole and in the form of meals and extracts. Kitabayashi *et al.* (1971a) used diets of 56–74% squid meal in their experiments with *P. japonicus*, while Deshimaru and Shigueno (1972) used diets with lower percentages (20–47%) for the same species which resulted in better growth than with diets containing fish meal. Both the feed efficiency and the survival reported by the Japanese authors exceeds that determined in this study under different conditions and with another species. Best growth was obtained with diets containing 5% or 15% squid meal, while with larger amounts of squid (30% and 49%) mortality was high and growth decreased.

These studies suggest the favourable response of shrimp to the addition of small amounts of squid meal in the feed. This component may thus be of economic potential in those areas of the world in which squid can be obtained at low cost.

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Nutritional Diseases in Channel Catfish

R. T. Lovell

Abstract

Nutritional diseases are uncommon among fish in the wild but have occurred when fish were confined in unnatural conditions and fed supplemental diets for rapid growth. The nutritional disease in channel catfish (*Ictalurus punctatus*) that has received most recognition is the 'broken-back syndrome' caused by a vitamin C deficiency Research at Auburn University has confirmed the role of vitamin C in broken-back syndrome. Other research at Auburn on nutritional disorders in channel catfish includes biotin and phosphorus deficiencies and protein excess. The first symptoms of the deficiency of any of the 14 essential vitamins in channel catfish are depressed appetite and reduced growth rate. Other common symptoms are discolouration, lack of co-ordination, nervousness, haemorrhage, lesions, fatty liver, and increased susceptibility to bacterial infections. Lipids and carbohydrates seriously influence the growth and condition of the fish.

Maladies nutritionnelles chez l'ictalure tacheté

Résumé

Quoique peu fréquentes chez les poissons sauvages, des maladies nutritionnelles surviennent lorsque les poissons se trouvent confinés en milieu artificiel et reçoivent une nourriture d'appoint destinée à en accélérer la croissance. Chez *Ictalurus punctatus*, la maladie nutritionnelle la plus fréquemment diagnostiquée est le 'syndrome du dos arqué', provoque par une carence de vitamine C. Des recherches realisées à l'Université d'Auburn ont confirmé le rôle de la vitamine C dans ce syndrome. On y a également etudié les carences de biotine, et de phosphore et les excès protéiques. La presence insuffisante de l'une des 14 vitamines essentielles pour cette espèce se manifeste au début par une perte d'appétit et une diminution du taux de croissance. Autres symptômes courants: modifications de la couleur, difficultes de coordination, nervosité, hémorragies, lésions, stéatose hépatique et vulnerabilité accrue aux infections bacteriennes. Les lipides et les glucides jouent un rôle important dans la croissance et l'état du poisson.

Enfermedades nutricionales en el bagre de canal

Extracto

Las enfermedades nutricionales son poco frecuentes entre los peces que viven silvestres, pero se han dado casos de ellas cuando los peces se crian en condiciones no naturales y se alimentan con dietas suplementarias para acelerar su crecimiento La enfermadad nutricional más conocida del bagre de canal (*Ictalurus punctatus*) es el 'sindrome de fractura de la columna vertebral', determinado por una deficiencia de vitamina C. Las investigaciones hechas en la Universidad de Auburn han confirmado la función de la vitamina C en el síndrome de fractura de la columna vertebral. En las investigaciones realizadas en Auburn sobre los trastornos nutricionales del bagre de canal se han estuadiado también las deficiencias de biotina y fósforo y el exceso de proteinas. En el bagre de canal, los primeros síntomas de la deficiencia de cualquiera de las 14 vitaminas esenciales son disminución del apetito y reducción del índice de crecimiento. Otros síntomas frecuentes son alteración del color, falta de coordinación, nerviosismo, hemorragias, lesiones, acumulación de grasa en el hígado y mayor susceptibilidad a las infecciones bacterianas. Los lípidos y los carbohidratos influyen seriamente en el crecimiento y el estado de los peces.

1 Introduction

Fish from the wild seldom show signs of nutritional diseases. This is because natural aquatic foods are fairly nutritious, especially in the essential growth factors like vitamins and minerals, and the fish's growth rate is limited to the amount of energy and protein in the natural foods. It is when fish are confined under unnatural conditions and fed supplemental feeds for fast growth that nutritional deficiency symptoms occur.

Nutritional diseases have not been a serious problem in pond culture of channel catfish (*Ictalurus punctatus*) primarily because, with moderate stocking conditions (2 000 kg standing crop/ha) the natural pond organisms satisfactorily supplement the artificial feeds with any deficient growth factor. However, as the culture environment deviates from the conventional pond system to intensive or artificial conditions, the availability of natural food decreases and the nutritional adequacy of the prepared feed provided becomes more critical. Several types of culture systems have emerged to commercial prominence for growing catfish under highly concentrated conditions, such as confinement in raceways, and suspended cages. It is when fish culturists attempt to use a nutritionally incomplete, supplemental-type ration to grow catfish in artificial or unconventional pond systems that nutritional diseases become manifest. On numerous occasions catfish have been brought to the Cooperative Fish Disease Laboratory at Auburn University, Auburn, Alabama with disease signs but without evidence of pathogen infestation. It was usually determined that the fish came from a modified culture system with limited natural food and the fish were fed a nutritionally incomplete diet.

2 Vitamins

Vitamins are essential growth factors, of organic composition, that are required in the diet in only very small quantities. Two of the first symptoms of a deficiency of practically any of the 14 vitamins that have been found to be essential for channel catfish are depressed appetite and reduced growth rate. Other symptoms are discoloration, lack of co-ordination, nervousness, haemorrhage, lesions, a fatty liver, and increased susceptibility to bacterial infections.

Deficiency symptoms for several nutrients have been

demonstrated experimentally. At Auburn University, purified diets and aquaria with flowing water were used to demonstrate clinical deficiency signs for 11 vitamins in channel catfish. Later, at the Southeastern Fish Cultural Laboratory, Fish and Wildlife Service, US Department of the Interior, Dupree (1966) confirmed these initial observations and subsequently determined quantitative requirements for several vitamins for channel catfish. Later studies at Mississippi State University (Wilson and Poe, 1973), the University of Georgia (Andrews, 1975, pers. comm., Andrews and Murai, 1975) and Auburn University (Lovell, 1973) have added more information on deficiency symptoms of 14 vitamins for channel catfish. A summary of results from these experiments is presented in Table I. Inositol deficiency produced skin lesions and haemorrhage in carp (Hepher, 1972) and poor growth in salmonids (Halver, 1972) but has not been found to be essential for channel catfish. Para-aminobenzoic acid has not been found to be essential for channel catfish or other cultured species (Hepher, 1972; Halver, 1972).

TABLE I
VITAMIN DEFICIENCY SYMPTOMS IN CHANNEL CATFISH[1]

Vitamin	*Deficiency symptoms*
A	Reduced growth, protruding and opaque eyes, fluid in body cavity, mortality
D_3	Reduced growth
E	Reduced growth, mortality, anaemia, muscular dystrophy, exudative diathesis, depigmentation
K	Haemorrhages on body surface
Thiamine	Reduced growth, nervousness, poor equilibrium, lethargy
Riboflavin	Reduced growth, opaque lens of eye, 'stubby' body, mortality
Niacin	Reduced growth, tetany, lethargy, mortality
Pyridoxine	Reduced growth, nervousness, tetany, erratic swimming, mortality
Pantothenic acid	Reduced growth, 'mummy-textured' skin, clubbed gills, erosion of lower jaw and fins, mortality
Folic acid	Reduced growth, lethargy, mortality
B_{12}	Reduced growth
Choline	Reduced growth, enlarged fatty liver, haemorrhagic kidneys
Ascorbic acid	Reduced growth, scoliosis, lordosis, eroded caudal fin, deformed gill operculum, slow wound repair, depigmentation
Biotin	Slightly reduced growth, fatty livers when fed high-lipid diet

[1] Sources: Dupree (1966); Wilson (1973); Andrews (1974, 1975, pers. comm.); Lovell (1973)

2.1 *The 'broken-back syndrome'*

One of the most dramatic instances of nutritional disease in commercial catfish culture was the 'broken-back syndrome' described by Meyer (1975). On many occasions channel catfish from hyperintensive culture systems were brought into disease diagnostic laboratories for determination of the cause of severely deformed spinal columns. The cause was suspected to be related to the diet but the exact nutritional deficiency was not determined until a study was conducted at Auburn University in 1971 to evaluate the effect of a deficiency of vitamin C (ascorbic acid) in a high-performance ration fed to channel catfish.

In this experiment, 1 600 channel catfish fingerlings were stocked in 1 m^3 suspended cages at a rate of 400 fish per cage and fed intensively for 180 days. Half of the fish were fed a diet that was nutritionally sufficient except for being low in vitamin C. The others received vitamin C supplement. At the end of the feeding period the fish receiving supplemental vitamin C had significantly superior weight gains, feed conversion ratios, and rate of survival (Table II).

Growth response of the fish fed the vitamin C-supplemented diet was excellent, so apparently the diet was nutritionally adequate. Mortality among the vitamin C-deficient fish was caused primarily by infestations of *Aeromonas hydrophila*.

Forty-five percent of the fish on the vitamin C-deficient diet had visually detectable deformities, which included scoliosis, lordosis, and depigmented areas on the backs. In severely deformed fish the vertebral column was separated or severely eroded and pronounced atrophy of the spinal cord was noted. In less severely deformed fish there were enlarged, spongy vertebrae, and hemivertebrae were often found. Many fish had internal haemorrhagic areas along the spinal column but appeared normal externally. Figures 1 and 2 show a photograph and radiograph of catfish with deformed spinal columns.

None of the fish had swimming irregularities or tetany. Histological examination of gill filaments indicated normal

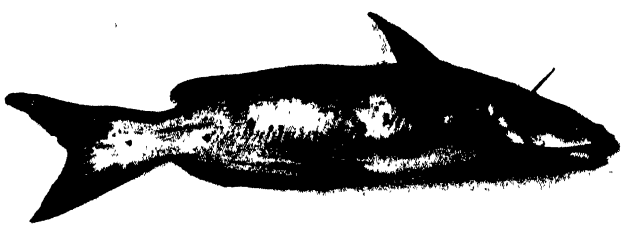


Fig. 1. Channel catfish with scoliosis and lordosis resulting from a dietary deficiency of vitamin C. Depigmented vertical band posterior to dorsal fin indicates area of damaged spinal column

TABLE II
WEIGHT GAIN, FEED CONVERSION RATIO (WEIGHT FEED/WEIGHT GAIN), SURVIVAL AND BODY DEFORMATION IN CAGED CHANNEL CATFISH FED DIETS WITH OR WITHOUT SUPPLEMENTAL VITAMIN C FOR 180 DAYS

Supplemental vitamin C	*Cage*	*Average weight gain (g)*	*Feed conversion ratio*	*Survival*[a] *(%)*	*Deformed fish*[b] *(%)*
Yes	1	537	1·27	100·0	3·2
	2	524	1·31	96·0	4·6
	Average	531	1·29	98·0	3·9
No	3	336	1·98	78·2	51·0
	4	326	1·80	77·4	39·0
	Average	331	1·88	77·8	45·0

[a] Survival since arrest of parasite infestation in early phase of this experiment
[b] Fish showing one or more of the symptoms of scoliosis, lordosis or depigmented area on back

development. No external lesions could be attributed to diet and no tissue damage, other than in areas along the spinal column, was detected by visual examination. Liver, anterior kidney, and blood analyses all reflected the differences in content of vitamin C in the diet.

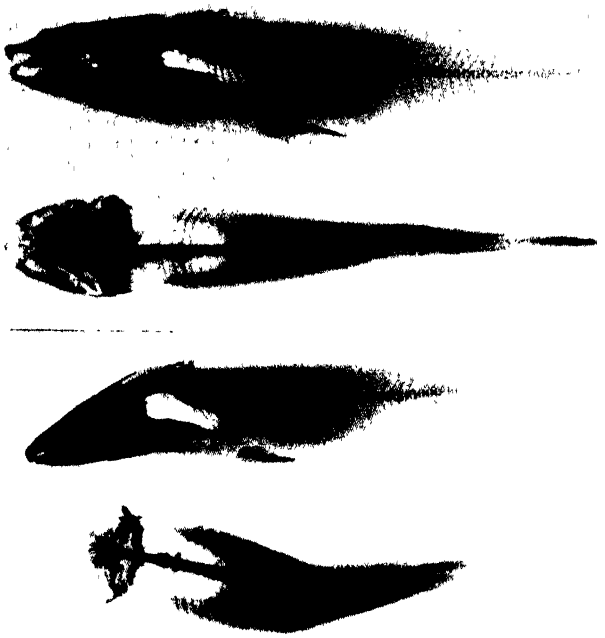


Fig 2. Radiographs of channel catfish with lordosis and scoliosis resulting from a dietary deficiency of vitamin C. Top. lateral and dorsal views of normal fish. Bottom: lateral and dorsal views of scorbutic fish

Monthly sampling indicated that differences in weight or physical conformation between fish fed the two diets were not manifested until after the twelfth week of the feeding period, or until the fish weighed 100–180 g.

The association between vitamin C and the broken-back syndrome was supported by Wilson and Poe (1973) who induced scoliosis and lordosis in channel catfish and demonstrated impaired collagen formation by depriving the fish of dietary vitamin C. A later study at Auburn University with purified diets in aquaria confirmed the role of vitamin C in the broken-back syndrome. After 8 weeks on a vitamin C-free diet, 8% of the fish had deformed spinal columns and after 22 weeks 85% of the fish showed this symptom. Other symptoms of vitamin C deficiency were slow rate of wound repair similar to that demonstrated in rainbow trout (Ashley, Halver and Smith, 1975), eroded caudal fin, deformed gill opercula and filaments, anaemia, and reduced tissue levels of ascorbic acid. The minimum dietary requirement of vitamin C for normal growth and health of channel catfish was found at Auburn University to be 30 mg/kg of ration. Andrews and Murai (1975) reported that 25–50 mg/kg was necessary.

Studies were conducted at Auburn University to determine the value of ascorbic acid in feeds for pond-fed channel catfish. As shown in Table III, when the maximum standing crop of fish per hectare was 9 880 (3 750 kg) or less, the fish did not need ascorbic acid in their feed. At densities of 24 700 fish (6 270 kg) per hectare (in ponds where water was exchanged) the absence of supplemental ascorbic acid in the feed resulted in fish with deformed backs, reduced growth rate, and greater sensitivity to pathogenic bacteria. Stocking tilapia, which competed for natural food, in another experiment with 9 800 channel catfish per hectare resulted in ascorbic acid deficiency symptoms in the catfish when the vitamin was not added to the feed.

Spinal damage in fish may result from other causes. Vitamin E deficiency caused lordosis in carp (Watanabe *et al*, 1970). Salmonids fed tryptophan-deficient diets developed spinal deformities (Halver, 1972). Exposure to sublethal levels of pesticides caused vertebral injuries in golden shiners (Meyer, 1966), bullheads (Mont and Boyle, 1969), and channel catfish (Mehrle and Mayer, 1975).

2.2 *Biotin*

Dietary deficiency symptoms for some nutrients in fish are subtle. The nutrient may be synthesized to some degree by the fish *in vivo* or by intestinal micro-organisms, so that normal growth occurs under some conditions but not under others. Biotin is not needed in normal or productive rations by man or most animals. Biotin is essential in practical rations for poultry to prevent perosis, and for trout to prevent 'blue slime patch' disease (Halver, 1972). Although a dietary need for biotin has been demonstrated with experimental diets for salmon, carp and eel (Halver, 1972), Dupree (1966) was unable to demonstrate a need for this vitamin in channel catfish.

Recently, at Auburn University, channel catfish were fed purified diets containing biotin, no biotin, or an anti-biotin factor (raw egg white), each with no dietary lipids or with 8% soybean oil (3 × 2 factorial design). Within 8 weeks fish receiving soybean oil in their diets had grown significantly more than those fed the lipid-free diets. Fish fed the lipid-free diet with raw egg white had grown least and were lethargic. Fish fed diets containing soybean oil with raw egg white showed a growth supression after the sixteenth week. Fish fed the lipid-free diets, with or without biotin, where the raw egg white was omitted, grew at the same rate throughout the 24 week experiment. Fish fed the soybean oil diets without raw egg white grew at the same rate for 20 weeks after which time those receiving biotin grew at a slightly faster rate. The results indicate appreciable intestinal synthesis of biotin in channel catfish. The reason that the fish receiving soybean oil in their diet needed additional biotin (more than provided by intestinal synthesis) and

TABLE III

WEIGHT GAIN, BODY DEFORMATION AND MORTALITY IN CHANNEL CATFISH FED RATIONS WITH AND WITHOUT VITAMIN C IN PONDS AT VARIOUS STOCKING DENSITIES AND IN CAGES

Culture system	*Number of fish stocked*	*Weight gain (kg)*		*Deformed fish (%)*		*Mortalities (%)*	
		Vitamin C added	*No vitamin C*	*Vitamin C added*	*No vitamin C*	*Vitamin C added*	*No vitamin C*
Pond	4 940/ha	0·52	0·54	Negative	Negative	5	5
Pond	7 410/ha	0·44	0·44	Negative	Negative	5	5
Pond	9 880/ha	0·38	0·39	Negative	Negative	5	15
Pond	24 700/ha	0·25	0·18	Negative	23	20	24
Cage	400/m^3	0·54	0·34	Negative	45	5	25

those fed the lipid-free diet did not, is probably the faster growth rate of the former.

3 Minerals

Fish absorb most minerals from the water relatively easily. Calcium and phosphorus are the minerals required in largest quantities by fish. Calcium can be absorbed from the water in adequate amounts to meet the fish's metabolic needs unless the water is unusually soft (Phillips, Podoliak and Brockway, 1956). However, phosphorus is not absorbed from the water quite as effectively as calcium and the low concentration of phosphorus found in water makes it necessary for fish to depend upon the diet for much of their need.

Dietary calcium and phosphorus requirements for channel catfish fingerlings were studied by Lovell (1975), in controlled environments with highly purified diets. A series of 10- and 12-week feeding trials was conducted in water at 26°C which contained 35 ppm of calcium hardness and 0·05 ppm of inorganic phosphorus. Fig. 3 shows that addition of calcium to the diet made relatively little difference in growth rate of the fish; however, increasing the phosphorus level from 0·1% to 0·4% of the diet resulted in a dramatic improvement in growth rate. A subsequent study was conducted to refine the knowledge regarding phosphorus requirements of channel catfish. Fig. 4 indicates that the minimum percentage of phosphorus in the diet for satisfactory growth appears to be slightly above 0·4. Gross examination of the fish revealed no signs of phosphorus deficiency other than decreased growth rate

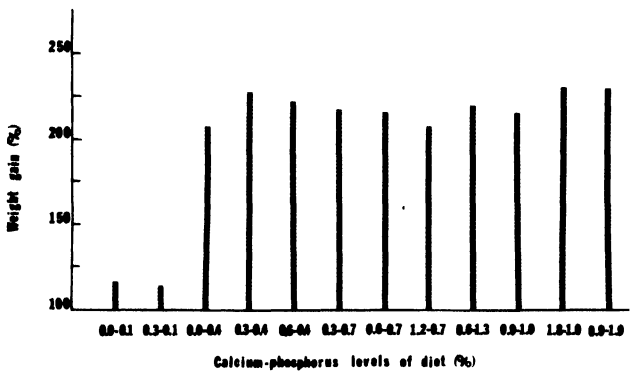


Fig 3. Weight gains of channel catfish fingerlings in a controlled aquatic environment fed semi-purified diets containing a range of percentages and ratios of calcium and phosphorus

and increased mortality, although percentage phosphorus in the bones increased as the dietary level increased beyond 0·5% phosphorus. According to Aoe[1], Japanese researchers found scoliosis in phosphorus-deficient carp.

To determine the importance of phosphorus in supplemental feeds for catfish cultured in ponds, an all-plant basic diet was prepared which contained 0·22% non-phytin phosphorus. The basic diet was supplemented with 0·3%, 0·6% and 0·9% phosphorus from dicalcium phosphate. The test diets were fed to channel catfish, stocked 7 400 per hectare, for 6 months. The fish fed the basic diet without supplemental phosphorus gained 12% less weight than those that received 0·3% phosphorus supplement in their diet. There was no improvement in fish growth when higher levels of

[1] Aoe, H., Nisshin Flour Milling Company, Research Laboratory, Saitama, Japan 1973

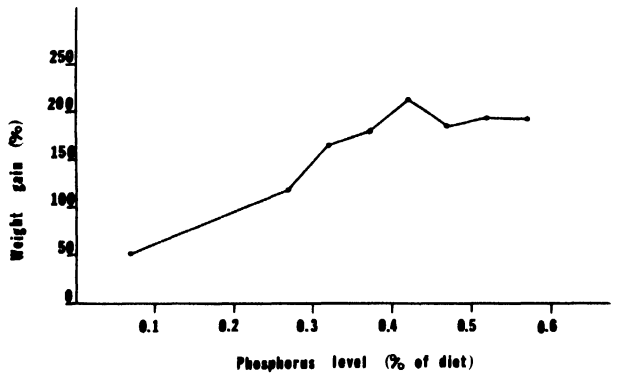


Fig 4. Weight gains of channel catfish fingerlings in a controlled aquatic environment fed semi-purified diets containing various percentages of phosphorus

phosphorus were added to the diet. This study indicated that levels beyond 0·52% available phosphorus are not necessary for channel catfish. The availability of phosphorus from various feed sources appears to be lower for fish than for farm animals. For example, fish meal phosphorus is highly available to livestock but Aoe claimed that digestibility of phosphorus in fish meal by carp, which does not have a gastric section in its digestive tract, is quite low. Cruz (1975) determined that the digestibility of phospho rus in fish meal by channel catfish was only 40%.

4 Lipids

Experiments on essential fatty acid requirements of trout have revealed a need for omega-3 fatty acids or the linolenic series instead of the omega-6 or linoleic series which is required by warm-blooded animals (Lee *et al*, 1967; Castell *et al*, 1972). A deficiency of omega-3 fatty acids in the diet caused discolouration, hypersensitivity to shock, and large livers. Specific fatty acid requirements of channel catfish have not been delineated; however, Dupree (1970) and Lovell (1971) found that the substitution of marine fish oils, which contain relatively high amounts of omega-3 fatty acids, with plant oils in catfish diets, improved growth rates of the fish. Conversely, Stickney and Andrews (1971) found that beef tallow triglycerides, which contain no omega-3 fatty acids, provided as much growth as an equal amount of menhaden oil triglyceride and more growth than several plant triglycerides in channel catfish diets. They also presented data to indicate that omega-3 or linolenic series had no unique nutritional importance to catfish (Stickney and Andrews, 1972).

In the study discussed previously on biotin requirements of channel catfish conducted at Auburn University, the fish fed a lipid-free diet gained markedly less weight than those receiving soybean oil in their diet; however, red blood cell volume, pigmentation, and liver size of the fish fed the lipid-free diet were normal.

Murai and Andrews (1974) reported that oxidized, polyunsaturated oil (menhaden oil) in the ration enhanced development of muscular dystrophy, exudative diathesis, depigmentation, poor growth and mortality in channel catfish, and increased their vitamin E requirement.

5 Protein

The major symptom of protein deficiency or amino acid imbalance in fish is reduced growth rate. Scoliosis was

demonstrated in salmon fed a tryptophan-deficient diet (Halver, 1972), but this is unlikely to occur with practical feeds.

A study at Auburn University (Prather and Lovell, 1972) showed that too high a level of protein, or too high a ratio of protein to energy in the diet, can depress growth rate of catfish. Channel catfish, stocked in earthen ponds at 7 400 per hectare, were fed rations containing three levels of protein, each at two energy levels. The growth responses after six months of feeding are shown in Table IV. Fish fed the high protein-low energy ration actually gained less than fish fed the low protein-low energy ration. This indicated that a high percentage of protein in catfish rations in the presence of a low amount of non-protein energy can be harmful to the fish.

TABLE IV
AVERAGE YIELDS AND FEED CONVERSION RATIOS FOR CHANNEL CATFISH FED DIETS CONTAINING THREE PERCENTAGES OF PROTEIN AT TWO ENERGY LEVELS FOR 6 MONTHS

Diets		*Average yield (kg/ha)*	*Average feed conversion*
% protein	*Kcal energy per kg*		
42	2 860	2 740	1 16
42	2 299	2 160	1·52
36	2 860	2 580	1·23
36	2 200	2 290	1·30
29	2 860	2 360	1·40
29	2 200	2 340	1 36

6 Carbohydrates

Yokote (1970) observed 'sekoke' disease in carp fed high starch rations. The symptoms were similar to those of diabetes melitis in warm-blooded animals. Fish do not utilize carbohydrates as well as protein or fats for energy, probably because of the relatively poor digestibility (Halver, 1972; Cruz, 1975). In fact, Cruz (1975) found that high levels of starch in the diet suppressed the digestion of protein, fat, and gross dietary energy. Phillips and Brockway (1956) found enlarged livers in trout fed high carbohydrate diets and recommended relatively low amounts of starch in trout rations. Simco and Cross (1966) reported enlarged livers in catfish on high carbohydrate diets, but did not indicate a depression of growth. Practical feed for channel catfish contain 30–40% carbohydrates (starch) from grains and grain byproducts and growth has generally been satisfactory. However, Moreira (1976) found that 40% corn in cooked (extrusion pelleted) catfish diets caused suppression of appetite and reduced growth rate. When he reduced the percentage of corn from 40% to 25% by substitution with fibre, food consumption and growth rate increased.

7 Conclusion

Nutritional diseases in fish occasionally occur when a toxic material is inadvertently added to a feed, such as the massive outbreak of cataract in rainbow trout (Orme[1]), or when an antinutritional factor is included in the ration, such as an antithiamine enzyme in raw fish parts (Camacho, 1974). But usually nutritional disorders in channel catfish occur when the fish are fed a high-performance diet in a highly unnatural environment, and an essential nutrient has been omitted, destroyed, or is not provided in sufficient quantity. The deficiency symptom is usually retarded rate of growth.

[1] Orme, L. E., Director, Spearfish Fisheries Center, U.S. Fish and Wildlife Service, Spearfish, U.S.A., 1974

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Chapter X Genetics and Genetic Improvement of Fish

Genetic Improvement in Aquaculture Industry

R. Moav

Abstract
Selective breeding and supporting genetic research in aquaculture throughout the world are reviewed, including: intra-population selection (including selection for disease resistance and behaviour characters), biometrical analysis of quantitative characters, intraspecific hybridization, inter-specific hybridization including sterile and monosex hybrids, genotype × environment interactions, genetic markers as tools in aquacultural genetic research and breeding, gynogenesis, polyploidy and mutagenesis. The review reveals that adequate genetic studies have not been undertaken, even with the most extensively studied fish such as common carp and trout.

Investigations into the genetics of carp indicate a wide intra-population genetic variation of a rather complex nature; the most conspicuous expressions of this complexity being absence of response to mass selection for fast growth rate and a strong heterosis in F_1 crossbreds. The large majority of organisms raised in aquaculture are also unselected wild stocks, while many of the hatchery bred stocks are highly inbred and probably suffer from the negative effects of inbreeding depression.

Present knowledge indicates that relatively simple steps may result in large-scale genetic improvement of commercial breeding stocks in aquaculture. Most promising of these are: crossbreeding to benefit from heterosis exploration and testing of new wild genetic stocks, interspecific hybridization to produce monosex and sterile hybrids, and the establishment of genetically sound and properly executed and controlled programmes of selective breeding. The use of genetic markers in breeding programmes and in supportive genetic research is strongly urged in order to minimize incorrect identification and stock contamination. Two current important major trends in fish farming are the transfer from traditional to modern and intensive husbandry, and the search for cheap, low quality by-products as substitutes for expensive fish feeds. Success in both trends is highly dependent on selection for specific adaptation to the newly imposed husbandry environment.

Amélioration génétique dans l'industrie aquicole
Résume
Le document passe en revue la sélection et la recherche génétique sur laquelle elle s'appuie dans le domaine de l'aquaculture mondiale, en examinant notamment les sujets ci-après: la selection intra-population soit pour accroître la resistance aux maladies soit pour développer certains caractères du comportement, l'analyse biometrique des caractères quantitatifs, l'hybridation intraspecifique, l'hybridation interspécifique y compris les lignées monohybrides et stériles, le genotype et les interactions écologiques, les marqueurs génétiques comme outils de la recherche et de la sélection génetique en aquaculture, la gynogenèse, la polyploïdie et la mutagénèse. Cet examen révèle l'insuffisance des recherches entreprises en génétique, même pour les poissons qui ont fait l'objet des études les plus extensives, tels que la carpe commune et la truite.

Les recherches menées sur la génétique de la carpe ont indiqué qu'il existe une grande variation génétique intra-population de nature assez complexe; les expressions les plus évidentes de cette complexité etant l'absence de réaction à la sélection de masse visant à obtenir des taux de croissance rapides et une forte hétérosis chez les hybrides F_1. La grande majorité des organismes élevés en aquaculture sont également des stocks sauvages non sélectionnés, alors que nombre des stocks reproduits en écloseries sont fortement consanguins et souffrent probablement des effets négatifs de la dégénérescence consanguine.

Les connaissances actuelles indiquent que des mesures relativement simples peuvent aboutir à une amélioration génétique considérable des stocks reproducteurs d'importance commerciale en aquaculture. Celles qui offrent les perspectives les plus prometteuses sont les suivantes: l'hybridation visant à tirer partie de l'hétérosis, la prospection et l'essai de nouveaux stocks génétiques sauvages, l'hybridation interspécifique visant à produire des lignées monohybrides et stériles, et la mise au point de programmes valables d'amélioration génétique convenablement exécutés et contrôlés. L'emploi de marqueurs génétiques et le recours à la recherche génétique dans les programmes d'élevage sont vivement recommandés afin de réduire au minimum l'identification incorrecte et la contamination des stocks. Deux tendances importantes se manifestent actuellement en pisciculture: l'évolution des techniques traditionnelles vers un élevage intensif et moderne et la recherche de sous-produits bon marché de qualité inférieure en remplacement des aliments du poisson plus coûteux. Dans les deux cas, la réussite dépend fortement de la sélection en vue d'une adaptation spécifique des poissons aux conditions nouvelles imposées à l'élevage.

Mejora genética en la industria acuícola
Extracto
Se examinan la aplicación de la selección genética a las activadades acuícolas en todo el mundo, y las investigaciones geneticas correspondientes, incluyendo: selección intrapoblacional, incluida seleccion para mejorar la resistencia a las enfermedades y fijar determinados caracteres de comportamiento; análisis biométrico de caracteres cuantitativos; hibridación intraespecifica; hibridación interespecifica, incluidos híbridos estériles y monosexuales, interacciones genotipo/medio ambiente; empleo de marcadores genéticos para la investigacion y la mejora genética en la acuicultura; ginogénesis, poliploidia y mutagenesis. El examen muestra que investigaciones genéticas adecuadas no han sido realizadas, incluso en el caso de los peces más estudiados, como la carpa común y la trucha.

Las investigaciones sobre la genética de la carpa han indicado una vasta variación genética intrapoblacional de carácter bastante complejo las manifestaciones más patentes de esa complejidad son la ausencia de respuesta a la selección masiva para conseguir una rápida tasa de crecimiento y una marcada heterosis en los cruces F_1. La gran mayoria de los organismos criados en acuicultura pertenecen a poblaciones silvestres y no seleccionadas, mientras en muchas de las poblaciones criadas en viveros hay un elevado grado de endogamia, y probablemente los peces sufren los efectos negativos de la depresión endogamica.

Los conocimientos actuales indican que con medidas relativamente sencillas pueden conseguirse en la acuicultura importantes mejoras genéticas de las poblaciones de reproductores. Las actividades más prometedoras son: cruzamientos para aprovechar la heterosis, exploración y ensayo de nuevas poblaciones geneticas silvestres, hibridación interespecifica para obtener hibridos monosexuales y estériles, y preparación de programas de mejora selectiva con una buena base genética y bien realizados y controlados. Se insiste en el empleo de marcadores genéticos en los programas de mejora y en las investigaciones genéticas correspondientes, para reducir al mínimo los casos de identificación inexacta y contaminación de poblaciones. Dos tendencias importantes en la piscicultura actual son: el paso de los sistemas tradicionales de crianza a los sistemas modernos e intensivos, y la búsqueda de subproductos baratos y de baja calidad para sustituir a los piensos para peces muy costosos. El éxito en ambos casos dependerá en buena parte de la selección para conseguir tipos que se adapten especificamente a las nuevas exigencias de la piscicultura.

1 Introduction

Genetic improvement, in its broadest definition, includes a wide range of activities and disciplines that are divided for convenience into the following main topics:

(*i*) *Selective breeding and genetic analysis of quantitative characters.* This section deals with selective breeding carried out by aquacultural breeders and research workers and with experiments designed to investigate the genetic control of production characters.

(*ii*) *Estimation of genotype × environment interactions.* Better understanding of the role played by genotype × environment interactions would help the aquaculturist to exploit a wider range of environments. More specifically, the breeder has to know how organisms selected in one environment would perform under the multitude of environments of commercial aquaculture.

(*iii*) *Hybridization.* The various types and objectives of hybridizing different genetic groups are discussed. The major topics are: breeding for heterosis, introgression, establishment of gene pools, distant hybridization and the specific subject of hybridizing in order to produce sterile or monosex populations.

(*iv*) *Use of genetic markers in breeding programmes and in genetic analysis.* Genetic markers may be subdivided into: morphological markers, electrophoretic

markers and antigenic markers. This section discusses how they can be used to facilitate genetic research and breeding operations—particularly in relation to lineage indentification and maintenance of the purity of selected breeding stocks.

(*v*) *Specific breeding aids: gynogenesis, polyploidy and mutagenesis.* Long experience in plant breeding plus experimental results in fish show that these three methods should play an important role in future aquaculture breeding.

Introduction of new species and the manipulation of polyculture systems—also included within the author's broad definition of genetic improvement—are not included in this review. Distant hybridization has a very extensive literature and frequently it is an enterprise of non-geneticists. Therefore, the subject will be discussed only briefly and with reference to genetic problems.

2 Selective breeding and genetic analysis of quantitative characters in aquacultural organisms

Aquacultural organisms have very high reproductive rates and large phenotypic variances. This combination makes mass selection for large size an easy task. As a result, selection for fast growth rate has been practised by many fish breeders. However, selection does not guarantee genetic improvement. Sometimes it may even indirectly result in poorer performance. To measure the effectiveness of a given selection scheme, specifically designed biometrical experiments have to be carried out. Far too few such experiments have actually been done in aquacultural research. Consequently, the information on gains made by past and current selection, as well as planned programmes, is quite insufficient.

2.1 *Mass selection in aquaculture breeding*

Mass selection is defined as selection based upon the characteristics of the individuals under selection, as opposed to that based upon the performance of their relatives. It is the simplest breeding method when the character to be improved is easy to measure. It is also most effective for high heritability characters. Nevertheless, a clear distinction should be made between controlled selection experiments and a fish breeder's selection; the latter referring to uncontrolled selection operations that may result in genetic gains but having no way of estimating their magnitude nor increasing general knowledge of genetics.

Of all aquaculture organisms, only the common carp (*Cyprinus carpio*) and trout have been bred for a sufficiently long time to be considered domestic races, and only with these species can past selection be evaluated.

2.1.1 *Selection of the common carp.* Carp farmers of Western Europe have been selecting the largest carp for hundreds of years (Schaperclaus, 1961; Moav and Wohlfarth, 1976). As a result, distinctive breeds have evolved having, as a rule, the mirror scale pattern (*ie*, frame of large scales around a naked body) controlled by a single recessive gene (Kirpichnikov, 1966). Scientists from the Federal Republic of Germany have formalized rigid procedures for sequential mass selection, beginning with yearlings and proceeding on to two- and three-year-olds. The largest individuals were selected but they also had to have the 'proper' body conformation—a high height/length ratio, a small number of scales, and no skeletal or fin deformities.

Soviet fish breeders have followed the procedures recommended by Schaperclaus (Golovinskaya, 1971), and several improved breeds seem to have been developed in different regions of the USSR (Kirpichnikov, 1966, 1971 and 1973).

2.1.2 *Selection of freshwater salmonid fishes.* The most popular and longest cultivated freshwater salmonids are the rainbow trout (*Salmo gairdneri*), the European brown trout (*Salmo trutta*) and the brook trout (*Salvelinus fontinalis*). The many trout hatcheries in the USA have practised selective breeding for high fecundity, large egg size, high hatching percentage, rapid growth and early maturity. Many claims of large genetic gains have been made. For example, the California Department of Fish and Game reported an almost 100% increase in number of rainbow trout spawning at two years of age, a doubling of the yearlings' weight and a fourfold increase in egg production of two-year-old females. Donaldson, the creator of the 'supertrout' in the USA, reported that his stocks excelled in almost every character of importance to the culturist (Donaldson and Olson, 1957; Donaldson, 1970).

Trout breeding programmes have also been reported in the USSR (Savostyanova, 1971), Denmark (Bregnvalle, 1963), Canada (Berst and Ihssen, 1973), Sweden (Aulstad, Gjedrem and Skjervold, 1972), and the Federal Republic of Germany (Steffens, 1974a).

2.1.3 *Selection of fish other than the common carp and trout.* Until recently, selection had been applied to only a limited number of fish groups. In 1949 Donaldson initiated a selection programme with the chinook salmon (*Oncorhynchus tshawytscha*). He reported large gains in faster growth rate, higher fecundity, quicker time of return, tolerance to high temperatures and disease resistance (Donaldson and Menasveta, 1961; Donaldson, 1970 and 1973).

The Atlantic salmon (*Salmo salar*) is under selection and genetic investigation in Canada (Dalziel and Shillington, 1961) and Sweden (Ryman, 1972; Gjedrem and Aulstad, 1974). Hatchery selection and preliminary studies are being carried out with the American ictalurid catfish (Sneed, 1971; Smitherman, Green and Pardue, 1974). Here a major selective goal is to reduce the relative size of the head. Selection of the marine flatfishes, plaice and sole (Order: Pleuronectiforms), has recently begun in Great Britain (White Fish Authority, 1967), and selection of coregonid fishes in the USSR (Nikolskii, 1961). Also, several other fish hatcheries and experimental stations are engaged to some degree in selective breeding, or are planning to do so.

2.1.4 *Selection of aquacultural organisms other than finfishes.* Selective breeding of lobster (*Homarus americanus*) was undertaken by the State Lobster Hatchery and Research Station, Vineyard Haven, Massachusetts, USA (Hughes, 1970). In Milford, Connecticut, genetic studies including a selection programme of the native American oyster (*Crassostrea virginica*) have been carried on for more than ten years (Longwell and Stiles, 1970; Stiles and Longwell, 1973). Frogs have been selectively bred at the University of Michigan (Nace, 1968; Culley and Gravois, 1969). Preliminary stages of genetic research of the freshwater shrimp (*Macrobrachium*) are under way in the

Florida Atlantic University, Boca Raton, Florida and in the University of Hawaii.

2.2 *Breeding for disease resistance in fish*

Intensification of fish farming makes diseases and parasites increasingly more difficult to control. Here, genetic resistance should play a significant role. Selection for disease resistance, particularly against infectious dropsy in the common carp, has been reported by Soviet workers (Kirpichnikov and Faktorovich, 1972; Kirpichnikov, 1971 and 1973).

Gjedrem and Aulstad (1974) reported significant differences between river strains of salmon parr (*Salmo salar*) in their resistance to vibrio disease. Heritability estimates, on an intra-river basis, were 0·12 and 0·07 from sire and dam components respectively. Strains of brook trout and brown trout have been shown to differ in their susceptibility to furunculosis (Embody and Hayford, 1925; Snieszko, Donhar and Bullock, 1959; Ehlinger, 1974) and to 'ulcer disease' (Wolf, 1954; Snieszko, Donhar and Bullock, 1959).

Five inbred strains and nine crossbred strains of the common carp were tested in 16 mixed ponds at Dor, Israel. One inbred strain was found to be infected by epidermal epithelioma disease and a second by a swim bladder inflammation. None of the remaining inbred and crossbred strains, including those between the two infected inbreds and between them and the other strains, suffered from either one of the two diseases (Hines *et al*, 1974).

2.3 *Breeding for behaviour characteristics in fish*

Anglers want fish that take bait or lines quickly and provide good sport, and these characteristics can be improved by selection and hybridization. Indications to this effect may be found in many reports. In the Netherlands, a club of amateur anglers participated in a long-term selection programme for improved 'sportsmanship' of carp (Beukema, 1970).

Wide intraspecific genetic variation in the ability to escape fishing nets were found in carp (Wohlfarth *et al*, 1975). Continuous harvesting of fish by seining or angling introduces selection for escapability, an economically undesirable trait. Thus, wild European carp (*Cyprinus carpio*) and the Chinese big-belly carp (the major Chinese race of *C. carpio*) are able to escape seines much better than do their relatives, the European domestic carp (*C. carpio*). The reasons for these differences are that wild European carp, as well as the Chinese big-belly carp, have been harvested by angling, seining, and other nets and traps. On the other hand, the European domestic breeds are harvested as a rule by emptying the ponds completely. Furthermore, selection of brood stocks is often made on samples collected in seine nets (Steffens, 1964; Wohlfarth *et al*, 1975).

Tilapia aurea is notorious for its ability to escape capture, and when ponds are being emptied for harvesting it hides in the mud. Its close relative, *T. nilotica*, is caught easily by seine nets and does not hide in the mud. Fortunately, the latter favourable characteristics are dominant so that the valuable hybrids between the two species (100% males) behave like their *T. nilotica* parents.

The anadromous Pacific (*Oncorhynchus*) and Atlantic (*Salmo salar*) salmon also offer interesting potential for genetic manipulation.

2.4 *Genetic analysis of quantitative traits in fish*

It should be re-emphasized that selection of breeding stocks, if not accompanied by proper controls enabling partitioning and estimation of genetic changes, cannot be considered a research endeavour in the sense that, as a rule, it does not result in increased knowledge of the relevant genetic control. To design efficient selection programmes and predict their expected gains, genetic analysis of the characters under study is required. Most production characters are the so-called quantitative or polygenic characters; that is, they are controlled by several to many genes, are strongly influenced by environmental variation, and have a continuous phenotypic expression. Therefore, the study of their genetic control requires biometrical analysis which helps gather basic information of the following general aspects, all of prime interest to the breeder: (*i*) Absolute and relative magnitudes of the variance component inherited in an additive fashion (heritability). Only this additive genetic variation responds to intra-population selection. (*ii*) Genetic and environmental correlations between characters of economic interest. (*iii*) The proportion of the total variance that is inherited in a non-additive manner. This component is caused by dominance and interactions between loci, and it can be captured by the breeder through the use of F_1 hybrids. (*iv*) Specific genetic adaptation to varying environments, *ie*, genotype × environment interactions.

Two basic experimental designs may provide the above information: (*i*) Comparative tests of different genetic groups, such as full-sib and half-sib families, inbred strains, open strains, *etc*. (*ii*) Properly controlled and sufficiently duplicated selection (preferably two-way) experiments. These experiments are more difficult to perform with aquacultural organisms than with common laboratory or even farm animals. For this reason, and others, little genetic analysis has been done with fish—negligible in comparison with major farm domestic animals—and only with common carp and salmonids. The available information is described below.

2.4.1 *Intrapopulation genetic analysis of quantitative characters of the common carp.* Soviet scientists were the first to use artificial fertilization in fish in order to reproduce full- and half-sib families for genetic analysis (Kirpichnikov, 1966). To estimate the breeding values of male parents, the eggs of a single female were divided into several lots, each fertilized by the milt of a different male. Similarly, to estimate the breeding values of female parents, the milt of one male was used to fertilize the eggs of several females. Each full-sib family was reared in a separate container. These tests showed genetic variation among the parents which could be used for selection of breeding stocks. However, the numbers of parents tested in these experiments were much too small to permit estimation of genetic variance components.

Every year since 1960 scientists in Israel have conducted large-scale genetic analyses of growth rate of 10–25 groups of carp, including full-sib families, inbreds, crossbreds and breeds introduced from Europe and the Far East (Wohlfarth *et al*, 1965; Moav and Wohlfarth, 1966 and 1973; Moav, Hulata and Wohlfarth, 1975). These tests have proved that even inbred lines of the domesticated European carp (including the Israeli breed) are very heterozygotic. Thus, the genetic variance component was

estimated to be 30–40% of the total phenotypic variance. This relatively large genetic variance component was mostly non-additive, *ie* it expressed itself in strong heterosis of F_1 crossbreds and in equally strong inbreeding depression when closely related individuals, such as full-sibs, were mated.

A fully-controlled, replicated, large-scale two-way selection experiment was undertaken for five generations, from 1965 to 1970 (Moav and Wohlfarth, 1976). The results showed that mass selection for fast growth rate yielded no response at all, while selection in the opposite direction—for slow growth rate—responded, corresponding to a realized heritability value of around 30%. Random-bred control lines of this experiment suffered a strong inbreeding depression and when, after five generations of separation, two were crossed, their F_1 progeny showed a high degree of heterosis. Subsequent tests from 1971 to 1974 of the line selected for fast growth rate showed that it still maintained a large genetic variance, and a limited family selection resulted, unexpectedly, in considerable improvement.

Intrapopulation competition in fish has been a generally recognized major contributor to the phenotypic variance of growth rate and its associated characters, such as gonad size and juvenile viability. Between 1961 and 1969 genetically diverse groups of carp were tested simultaneously in separate and mixed ponds (after marking by branding). A complete genetic correlation was found between relative growth rate under intergroup competition in mixed ponds and in its absence, in separate ponds. It was concluded that the major effect of intrapopulation competition in carp is to magnify existing genetically- and environmentally-induced differences (Moav and Wohlfarth, 1974). The practical implication of this result is that selection for increased yield capacity in carp can be performed more effectively in mixed ponds than in separate ponds. Obviously, this is a very convenient feature because much higher selection intensities can be applied when the units under selection are stocked in a single pond. Extrapopulation competition with other fish species, such as trout or catfish, having different ecological and ethological characteristics, would be unjustified. Therefore, similar experiments should be carred out with other major fish species. Moav and Wohlfarth (1974) discuss intrapopulation competition in fish and describe a theoretical model for partitioning competition-induced interaction into a regression function of yield capacity and an 'independent aggressiveness'.

A two-way selection experiment in carp for the ratio of body height to length (H:L) showed selection gains in both directions corresponding to realized heritability of around 40% (Wohlfarth, Ankorion and Moav, 1971). The genetic correlations of growth rate with this character and several other body conformation characters were around zero (Ankorion, 1966). In fact, the progeny of the parents selected for high H:L ratio were somewhat smaller than their controls. This finding, plus similar ones by Stegman (1958) questioned the usefulness of the strong emphasis placed upon 'proper conformation' by European carp breeders (Schaperclaus, 1961). Also, the argument that a high H:L ratio improves carcass quality is rather questionable.

The numerous intermuscular bones of many fish species have a negative effect on marketing. Lieder (1961) appears to be the first to report on the possibility of reducing the number of intermuscular (IM) bones in carp by selective breeding, but the finding of only a small phenotypic variation reduced his optimism. The first to use a large sample with the object of selecting carp with a reduced number of IM bones was Von Sengbusch (1963). He and his coworkers studied X-ray photographs of hundreds of carp, counted their IM bones and found a relatively wide phenotypic variation, ranging from 70 to 135. Kossman (1972) partitioned a significant genetic component for IM bones from eight full-sib families, all belonging to the German domestic carp.

In 1971 and 1972, Israeli scientists counted the numbers of IM bones in X-ray photographs of well over 1 000 carp belonging to 18 genetic groups including closed lines and crossbreds of both the European domestic carp and the Chinese big-belly carp (Moav, Finkel and Wohlfarth, 1975). Despite the wide genetic background, a surprisingly small phenotypic and practically no genetic variations were found. This result is in complete contrast to the observations of German workers. While the latter would justify selection to reduce IM bones in carp, the Israeli results led to the opposite conclusion. Obviously, more exploratory research is needed to breed carp without IM bones.

Another way to improve the table quality of carp is to reduce its fat content. Ankorion, Moav and Wohlfarth (1967) devised a rapid method of testing fat content in dead as well as live fish. In large-scale tests, wide intrapopulation phenotypic variance and large environmental effects were found, but only a small genetic component (unpublished results). It appears that the control of this character in carp is more complex than in common domestic farm animals, where it has a high heritability value. At least for the present, fish will have to be kept lean by proper management rather than genetic changes.

2.4.2 *Intrapopulation genetic analysis of quantitative characters in salmonid fishes.* A relatively large number of research institutes and hatcheries throughout the world conduct research and selection programmes on various salmonid species. Considering this and the vast economic importance of the group and its biological complexity, it is surprising that so little quantitative genetic work has been done with salmonids.

Gall (1975) studied two domestic strains of rainbow trout and their F_1 and F_2 backcross generations, in order to estimate genetic parameters of reproductive performance of hatchery cultured stocks. From full-sib families he estimated heritabilities, dominance and epistatic variance components, and genetic, environmental and phenotypic correlations. These estimates indicated that genetic improvement of growth and reproduction would be possible with only a few antagonistic complications, and that selection for egg volume may be the most effective means of improving reproductive performance.

Aulstad, Gjedrem and Skjervold (1972) studied variation in growth characteristics of the rainbow trout. With a factorial mating design, the additive, dominance and interaction variance components were partitioned. They also conducted an inbreeding experiment by full-sib matings. Their estimates of heritability of growth rate measurements ranged from 0·0 to 0·4, and the sire × dam interaction component was negative, indicating that non-additive gene effects were unimportant. Inbreeding depression was found for egg mortality but not for body weight.

Ryman (1972) studied the genetics of weight gain of

hatchery-reared full-sib families of Atlantic salmon (*Salmo salar*) that descended from and were released to, the River Indal Salven in Sweden. The fish were recaptured in the Baltic Sea during the second and third winters after release. The analysis was complicated by differences in release weights (for methods of correcting for differences in initial weights see Moav and Wohlfarth, 1973). The genetic component of variation of weight differences was small and seemed to be of secondary importance.

2.4.3 *Selection experiments in laboratory fish.* Small aquaria fish have served for many more than 50 years as laboratory animals in numerous studies of classical genetics with excellent and well known contributions (Kosswig, 1973), yet there is only one genetic analysis of growth rate in the guppy fish (Ryman, 1973). Ryman conducted a two-way selection experiment for body weight at 63 days for nine generations. He started with a base population in which sib analysis did not reveal additive genetic variation. Selection between full-sibs within aquaria was practised. Only a weak response was obtained—smaller than differences between generation means. This experiment exemplifies the great importance of 'laboratory fish' for pilot genetic studies. Ryman concluded '. . . if these results . . . are valid also for more economically valuable culture fish species, an increase of the breeding yield is not expected to be very easily obtained through exploitation of the component of additive genetic variation'. This conclusion is very similar to that which emerged from carp selection experiments conducted by Moav and Wohlfarth (1973 and 1976). A second important conclusion, equally valid for both carp and guppy fish, was that, despite the heritability realized, indications were found of the presence of real genetic differences between full-sib litters within lines. This suggests that non-additive genetic variation could be more important than additive variation.

2.5 *Selection: discussion and conclusions*

The experiments reviewed in the previous sections clearly show that the generally held belief that mass selection for growth rate easily yields quick and large genetic gains in fish, is unjustified. Large phenotypic variance of size distribution is commonly found in fish. Evidence also exists for large total genetic variance. Both observations are intuitively associated with expectations of selection gains, thus greatly contributing to the present confusion. Therefore, it cannot be overstressed that phenotypic, or even overall genetic variation is not sufficient for a successful selection programme.

Usually, reproductive traits of domestic and most laboratory animals hardly respond to selection. The generally accepted reason for this failure is that traits closely associated with reproductive fitness had reached selection plateau through natural selection. At the same time, selection for faster growth rate has generally been very successful. Thus, growth rate in carp, guppy fish and probably other groups of fish, behaves in a similar manner to reproductive traits, and this similarity is a key to understanding the genetic control of growth rate in fish. The strong positive correlation between body size and egg number in fish (Bagenal, 1967; Hulata, Moav and Wohlfarth, 1974) means that selection for body weight is an indirect selection for fecundity. Also, the overwhelming majority of fish hatchlings die within a short period after hatching and most of the survivors are the fastest growing in the pond. Thus, early fast growth rate and large body weight are major components of reproductive fitness and both could have reached selection plateau through natural selection. In the domestic European carp and possibly in the domestic breeds of trout, artificial selection for fast growth rate has operated in the same direction as natural selection. Therefore, the question to be asked is: how much, and in what way, could artificial selection of the largest individuals add to what natural selection has been doing without the helping hand of the breeder?

Comparative studies of growth rate of non-selected (wild European and cultivated Chinese) carps with selected carps revealed that artificial selection was effective in increasing only late growth rate, *ie*, after the onset of sexual maturation (Steffens, 1974; Moav, Hulata and Wohlfarth, 1974). This evidence indicates that early and late growth rates in carp are partially controlled by different genes and that negative genetic correlation between the two could, if present, contribute to the maintenance of genetic variability at the plateau for fast growth rate.

3 Genotype × environment interactions: the genetic aspect of adaptation to new environments

Genotype × environment (GE) interactions pose a major problem to the breeder since strains that do well in one environment may perform poorly in another. The major types of GE of potential interest to the aquaculture breeder may be classified as follows:

(*i*) *Genotype × pond interactions.* These include water quality, soil type, history of the pond, climate, topography, *etc.* This GE type was estimated for more than ten years in tests covering a wide range of fish farming in Israel, and it was found that among different strains of the domestic European carp these interactions were relatively small (Wohlfarth *et al,* 1965; Moav and Wohlfarth, 1973). When, however, a representative of the Chinese big-belly race of the common carp and its hybrids with the European carp were added to the tests, they exhibited very strong interactions (Moav, Hulata and Wohlfarth, 1975).

(*ii*) *Genotype × season interactions.* These interactions appear to be of considerable magnitude in carp (Wohlfarth, Lahman and Moav, 1964; Wohlfarth, Ankorion and Moav, 1971). Their important implication to the breeder is that measurements of genetic variability based upon a single season are unreliable.

(*iii*) *Genotype × age interactions.* Genetic differences in the shape of growth curves are expressible as genotype × age interactions. These are frequently found among different geographical races and between domestic and wild breeds (Steffens, 1974; Moav, Hulata and Wohlfarth, 1974). It should be noted that, in simple genetic tests, the last two interaction types are usually confounded.

(*iv*) *Genotype × husbandry system interactions.* Fish of the same species are often cultivated under widely different husbandry conditions, such as in ponds with stagnant or flowing water, aerated ponds, large water reservoirs, cages, with or without feeding, *etc.* Each husbandry system put a stress on a different component character of the yield. For example, in a crowded pond filled with stagnant water tolerance to low oxygen is of prime importance, while it is completely unnecessary in flowing water. Thus, different strains may have to be selected for different culture

systems. Considerable differences have been found between the rankings of growth rate of the same strains and crossbreds of carp when grown in ponds or cages (Moav and Wohlfarth, 1976). Similarly, some catfish species and their hybrids performed differently in aquaria from ponds. A notable example is the blue catfish (*Ictalurus furcatus*) which competes with the channel catfish (*Ictalurus punctatus*) in ponds, lakes and rivers, but performs poorly in aquaria (Sneed, 1971).

(*v*) *Genotype* × *competition interaction.* Crowding produces competition for limited external resources. Genetic variability in the ability to withstand competition creates genotype × competition interactions. These interactions are of major importance to the breeder when he designs selection procedures and growth rate tests, and when he breeds for adaptation to polyculture (Moav and Wohlfarth, 1973 and 1974).

3.1 *Simultaneous modification of the environment and the genotype*

Aquaculture is currently undergoing almost revolutionary changes throughout most parts of the world. In addition to domestication of new organisms that have to adapt to managed environments, these changes take two general directions. The first is a change from traditional, low-yielding fish farms to modern, high-input, high-yielding farms. Simultaneously, because of the great rise in the cost of high-quality feed, modern fish husbandry is 'shifting down' to the use of cheaper, low-quality waste products while maintaining high yields. Moav *et al* (1976) have shown that, when a wide range of culture systems is involved, powerful genotype × environment interactions are to be expected. This holds true particularly for finfish aquaculture where culture systems range from raising the fish in ponds of stagnant water without feeding or manuring to crowding them in cages in rivers and feeding with protein-rich feeds. The yields per hectare of water surface area of these two extreme systems are, respectively, a few hundred kilogrammes and around 2 000 tons. The strong genotype × husbandry interactions make the conventional assertion that 'improved management is the major and primary requirement for increasing production and that genetic improvement can provide only the final "fine-tuning" of the system' unjustified and misleading. Furthermore, the view that genetics and husbandry are two independent approaches to increased production is wrong. To ensure a successful transition from one husbandry level to the next, the two have to be considered as inseparable components of a single process.

4 Hybridization

Fisheries biologists and fish farmers have performed an almost uncountable number of intraspecific, interspecific and more distant hybridization whose potential benefits for the breeder may include: (*i*) hybrid vigour in F_1 hybrids; (*ii*) introgression, *ie*, the transfer of a small number of genes from one genetic group to another in order to 'correct' specific faults; (*iii*) creation of a wide gene pool as a broad base for future selection; (*iv*) combination, in a single fish, of specific qualities of different species; (*v*) sterile and monosex hybrids.

4.1 *Breeding for heterosis in F_1 hybrids*

Heterosis or hybrid vigour enables an offspring to surpass both its parents. Inbreeding depression, on the other hand, is a mating of closely related parents that has a deleterious effect on the progeny. By definition, the one never comes without the other. The two phenomena are almost universally distributed in plants and animals and are especially conspicuous in traits closely associated with reproductive fitness.

In Israeli studies of carp genetics, many comparisons have been made between the growth rate of inbreds and that of their crossbred offspring. Almost every single brother-sister mating showed marked inbreeding depression expressed as reduced growth rate, increased mortality and increased proportion of skeletal deformities (Moav and Wohlfarth, 1966; Moav, Hulata and Wohlfarth, 1975; Wohlfarth, Ankorion and Moav, 1971). Similar results were found by several Soviet workers (Kirpichnikov, 1971; Golovinskaya, 1971).

The economic losses caused by inbreeding depression in the major cultivated species are probably rather extensive. This is augmented by: (*i*) the very small breeding populations of fish kept by many breeders, which accelerates the rate of inbreeding; and (*ii*) avoiding introduction of fish from outside sources, because of veterinary reasons and the still widely-held belief that 'mixing' of breeds has intrinsic harmful effects. Although the published information on fish other than carp is rather limited, it strongly indicates that heterosis and inbreeding depression should be considered in breeding programmes. Even in oysters, survival and growth rate of outbred larvae were significantly better than those of inbreds (Longwell and Stiles, 1973).

Extrapolating from the evidence found in carp, it can be concluded that the single step of mating unrelated individuals for the production of commercial fry should improve growth rate, viability and uniformity in many aquaculture farms. The simplest testing for superior crossbreds is to collect existing strains from different breeding farms, hatcheries and natural bodies of water and test them under a uniform environment. The best crossbreds may be put to an immediate commercial use. In Israel, such a programme was started in 1960 and by 1962 it was possible to distribute large quantities of F_1 fry to commercial farms with excellent results (Moav and Wohlfarth, 1966; Wohlfarth *et al*, 1965).

4.2 *Introgression of genes from one genetic group to another*

Introgression is used as a breeding tool when one breed (or race or species) is superior to others in most of its characters, but it can be further improved or 'corrected' by specific substitution of a few genes. This technique is popular in plant breeding, for example, for the transfer of genes for disease resistance from wild species to their cultivated relatives. In aquaculture it should be used similarly. Thus, Soviet scientists transferred genes for different body colours (to serve as genetic markers), from the Japanese ornamental carp to commercial carp breeds (Katasonov, 1974).

4.3 *Wide gene pools as starting populations for selection programmes*

The most common application of intraspecific hybridization in fish is the creation of a hybrid population involving two or more different breeds and selecting from successive generations of segregating hybrid populations. This method

has been used extensively by Soviet fish breeders (Nikoljukin, 1971a; Golovinskaya, 1971).

4.4 *Hybridization between the Chinese and European races of the common carp—a case study*

A thorough analysis of genetic variation between distinctly separated groups of a single fish species was carried out on the differences between the Chinese big-belly race and the domesticated European race of the common carp (Hulata, Moav and Wohlfarth, 1974 and 1976; Moav, Hulata and Wohlfarth, 1974 and 1975; Moav, Finkel and Wohlfarth, 1975; Wohlfarth *et al*, 1975; Wohlfarth, Moav and Hulata, 1975; Moav *et al*, 1976 and 1979). This research project was initiated in 1970 with the introduction of several hundred big-belly carp fry from Taiwan Province of China. Testing the two races, their F_1, F_2 and backcross hybrid generations enabled distinction and measurement of interracial differences in many characters. These differences, their dominance magnitude and direction (Table I), show a multi-character genetic profile the recognition of which pointed to the usefulness for the breeder of hybrid derivatives of the two races. The most prominent features of this profile may be summarized as follows:

(*i*) The juvenile (first three months after hatching) growth rate of the Chinese big-belly carp was higher than that of the European race.

(*ii*) The post-juvenile growth rate of the European carp was, under most circumstances, much higher than that of the big-belly carp.

(*iii*) Crowded pond conditions, where dissolved oxygen and added feeds were insufficient, had a much less depressing effect on the growth rate of the big-belly carp than on that of the European carp. Under these conditions, their hybrids showed very strong heterosis.

(*iv*) When stocked in cages, relative growth rate of the big-belly carp was adversely affected to a high degree.

(*v*) The European carp showed a considerably higher responsiveness to improved pond conditions (husbandry inputs).

(*vi*) Weight difference between females and males was 40% in the big-belly carp and only 15% in the European carp.

(*vii*) The big-belly carp showed a much higher capability to escape seine nets.

(*viii*) Viability of the big-belly carp was considerably higher in all environments, the difference being most pronounced in crowded ponds.

(*ix*) The body of the big-belly carp is longer (lower body height:length ratio) than that of the European carp although it has one vertebra less.

(*x*) The big-belly carp has the wild-type full scale cover, while most of the domesticated European breeds have the mirror-type scale pattern.

(*xi*) The big-belly carp tends to accumulate more fat than the European carp.

(*xii*) The big-belly carp reaches sexual maturity earlier than the European carp, it has bigger eggs, and a much higher ratio of gonad to body weight. In general, overall fertility and reproductivity are much higher in the big-belly carp.

(*xiii*) In most of the electrophoretic protein loci studies so far, the two races have had different alleles.

In summary, the big-belly carp excels in all aspects related to reproductivity, viability and adaptation to harsh pond conditions, while the European carp is more capable of growing faster when appropriate husbandry inputs are supplied. The above multi-character variation between the two races may be explained in terms of their respective adaptive evolution in response to diverse carp farming systems (Wohlfarth, Moav and Hulata, 1975).

Under the European carp farming system of monoculture, with low stocking rates and high feeding levels, the slow growing, early maturing big-belly carp has little to offer to the breeder. However, in recent years a trend away from monoculture to polyculture and from high-cost feeds to cheap by-products, including manure, is rapidly gaining popularity. Under the latter conditions, the combination of the European carp's fast growth rate and late sexual maturity with the Chinese carp's viability, high resistance to crowding and adaptability to low-grade feeds along with a strong heterosis, make hybrid derivatives between the two races very valuable. In order to benefit from the good qualities of the big-belly carp, while yielding to the local demand for 'mirror' type scale pattern, a mirror line with 75% big-belly carp genes has already been produced. F_1 Chinese × European carp crossbreds also have a great potential for genetic improvement in the traditional fish ponds of southwest Asia (Moav *et al*, 1979).

4.5 *Interspecific hybridization*

Numerous distant hybridizations have been made in many groups of fish. The primary object of many of these was to

TABLE I

RELATIVE MAGNITUDE OF GENETIC DIFFERENCES BETWEEN THF EUROPEAN AND CHINESE RACES OF THE COMMON CARP AND THEIR F_1 HYBRID

Characters	*European*	*Chinese*	*F_1 hybrid*
Growth rate			
— juvenile (first three months after hatching)	low	high	high
— post-juvenile	high	low	high–
— tolerance to crowded, low-input pond conditions	low	high	high+
— in cages	high	low	intermediate
— responsiveness to husbandry inputs	high	low	intermediate
Weight differences: female minus male	small	big	intermediate
Seine escape ability	low	high	intermediate
Viability	low	high	high–
Body shape: height/length	high	low	intermediate
Mean number of vertebrae	33·6	35	34
Scale cover	mirror	full	full
Proportion of fat	low	high	intermediate
Egg size	small	big	intermediate
Gonad weight/body weight	low	high	intermediate
Onset of sexual maturity	late	early	late–
Overall productivity	low	high	intermediate
Electrophoretic proteins: differences found in several systems			

investigate the systematic relationships and macro-evolution of the groups involved. Only a few selected examples of interest to aquaculturists are described here. Buss and Wright (1956) conducted a hybridization programme among the four major trout species and the landlocked salmon (*Salmo salar*). Simon and Noble (1968) studied the inheritance of several traits in artificial crosses of chum (*Oncorhynchus keta*) and pink salmon (*O. gorbuscha*). Foerster (1968), who summarized a very extensive hybridization study of five Pacific (*Oncorhynchus*) salmon species, concluded that: '. . . the sockeye (*O. nerka*) is reputed to be the most valuable species for canning purposes but it does not mature until its fourth or fifth year. The pink salmon, of inferior quality when processed, matures in its second year. Therefore, if by interbreeding . . . the quality of the pink salmon could be improved without changing its age at maturity, great commercial benefit would accrue. Or, again, the chum salmon is much larger than the sockeye but its flesh is of lower quality when canned. . . . If, by crossbreeding these two species, the size of the sockeye were increased without loss of quality. . . ., a superior race of salmon would result'.

The splake, a cross between the lake trout (*Salvelinus namaycush*) and the eastern brook trout (*S. fontinalis*), is a good example of a successful hybrid (Christie, 1960; Ayles, 1974) When stocked in the Great Lakes as a replacement for the indigenous lake trout that have almost been eliminated by the parasitic sea lamprey, it occupied a different water zone and in this way was able to escape infestation by the lamprey.

Suzuki and Fukuda (1973) have made many crosses among six salmonid species (*Salvelinus pluvius, S. fontinalis, Oncorhynchus rhodurus, O. masou, O. nerka* and *Salmo trutta*). Some of the sterile hybrids had a higher body weight after removal of the viscera than did their parents. They also assumed a silvery lustre desirable for smoltification and their muscles retained their reddish-orange colour even when they reached the third autumn.

Many interspecific, intergeneric and intertribal hybrids were produced among the sunfishes (Centrarchidae), including some species of economic importance, particularly as sport fishes in the USA. Heterosis, sterility and irregular sex ratios were found (Childers, 1971).

Chaudhuri (1971) surveyed hybridizations in the Cyprinidae, particularly the major Indian and Chinese carp. Many of these species are under cultivation for long periods but unlike their relative, the common carp, they fail to reproduce in ponds and this has prevented their selective breeding and true domestication. The successful induction of spawning by injection of fish pituitary hormones facilitated hybridization by artificial fertilization (Alikunhi and Chaudhuri, 1959). Major hybridization work with cyprinid and cobitid fishes has been carried out in Japan (Suzuki, 1968 and 1973). American catfishes (*Ictalurus*) have gained considerable economic importance in the warm waters of the USA. Hybridization in this genus was started about 13 years ago in Marion, Alabama. Sneed (1971) reported the results of 24 different hybrid combinations among seven species of freshwater catfish. The white catfish (*Ictalurus catus*) × channel catfish (*I. punctatus*) hybrid was the most promising. It showed heterosis in growth rate and feed efficiency and did not have the undesirable large bull-head of the white catfish. Some of the hybrids appeared to have higher tolerance to low oxygen than either the channel or white catfishes.

Nikoljukin (1971 and 1971a) surveyed the hybridization work in fish culture in the USSR. It included interesting crosses between *Carassius* and *Cyprinus*, and between the various sturgeon (Acipenseridae). Some hybrids of the last group appear to be valuable, *ie*, the beluga × stellate (*Huso huso* × *Acipenser stellate*) hybrid has a wide range of adaptability enabling it to grow successfully in freshwater ponds, in brackish water and in the salt waters of the Azov Sea.

4.6 *Sterile and monosex hybrids*

Strong, fast-growing, yet sterile F_1 hybrids have an enormous potential for aquaculture. Their primary advantage is that they are the best solution to unwanted reproduction and overpopulation in ponds and lakes. A secondary advantage of sterile fish is that they do not spend energy on gonad growth and reproductive activities. Hence, they have more efficient food conversion, are meatier, and reach a larger size. The superior quality of hybrids has already been mentioned (Suzuki and Fukuda, 1973). In practically every group of the major cultivated fish, sterile hybrids of economic potential occur. More attention should be given to testing their usefulness for aquaculture.

Another approach to the problem of unwanted reproduction and overpopulation is mono-sexuality. When the single sex is the faster growing one, an extra advantage is offered. For example, in the important African genus *Tilapia*, several interspecific crosses produce 100% male hybrids and the males are 25–30% larger than the females (Hickling, 1967; Pruginin *et al*, 1975). Early sexual maturity and very high fecundity have long been recognized as the major obstacles to attaining higher yield with *Tilapia*. Pruginin *et al* (1975) listed all the published sex-ratios in *Tilapia* hybrids. Reciprocal crosses were performed in four of these combinations and all resulted in a 1:3 (75% males) sex ratio. Seven additional hybrids yielded excess males while a significant excess of females has not been observed in any F_1 hybrid. Two excellent experiments conducted by Chen (1969) and Jalabert, Kammacher and Lessent (1971) showed that sex determination involving two 'female' (X and W) and two 'male' (Y and Z) sex chromosomes fit the observed results in *Tilapia* hybrids best.

At present, all-male hybrid populations are available for commercial farmers only in Malaysia (*T. mossambica* × *T. hornorum*, supplied by the Tropical Fish Culture Research Institute, Malacca), in Israel (*T. nilotica* × *T. aurea*) and in Brazil (*T. nilotica* × *T. hornorum*) (Lovshin and Da Silva, 1976).

Excess males were found in hybrids of other groups of fish, among them the sunfishes (Childers, 1971; Lagler and Steinmetz, 1957), and in Cyprinidae (Suzuki, 1968).

The first and best analysed chromosomal mechanism of sex determination in fish is that of the small Central American freshwater platyfish (*Xiphophorus maculatus*), where two female (X and W) and one male (Y) chromosomes were found in natural populations. These combine to produce three female genotypes (XX, YW, and WW) and two male genotypes (XY and YY), and the mating XX and YY produces 100% males (Kallman, 1973). A major, if not predominant, sex determination mechanism in teleost fishes is homogametic (WW) females and heterogametic (XY) males. It was found in several groups in addition to *Xiphophorus*, among them, for example, the rice fish, medaka

(*Oryzias latipes*) (Yamamoto and Onitake, 1975) and the goldfish, *Carassius auratus* (Yamamoto, 1975).

5 Genetic markers—applications to genetic research and breeding programmes

Genetic markers of potential usefulness to the breeder may be classified into three classes: (*i*) morphological markers, particularly colour markers; (*ii*) electrophoretically distinguishable proteins; and (*iii*) blood group antigens.

They may serve as a valuable tool for the following applications:

(*i*) To discover pleiotropic effects of the marker loci on production characters. This application has not been notably successful to date (Utter, Hodgins and Allendorf, 1974).

(*ii*) To study, in a Mendelian fashion, polygenes that are closely linked to marker genes (Soller, Brody and Genizi, 1976). It is not expected that this application will have more than a limited impact on animal breeding in the near future.

(*iii*) To estimate the degree of inbreeding in breeding stocks.

(*iv*) To estimate relative genetic differences between related groups—a useful tool in hybridization experiments (Utter, Hodgins and Allendorf, 1974).

(*v*) To identify selected lines of breeding stocks, *ie*, a unique genetic brand (fingerprint) may be given to all the individuals of a given line by breeding selectively for homozygosity of different alleles at several loci in each line. Such a possibility already exists for the rainbow trout (Utter, Hodgins and Allendorf, 1974) and for the common carp (Kirpichnikov, 1973a). Maintenance of the purity of parental lines of heterotic F_1 hybrid fish by genetic markers is a necessary prerequisite for selection and commercial distribution of such lines. This technique has already been applied in Israel for guaranteeing the purity of *Tilapia aurea* males and *T. nilotica* females used as parents for the commercial production of 100% male hybrid progeny (Avtalion, Pruginin and Rothbard, 1975). Prior to application of this technique, hybrid derivatives regularly infiltrated the pure species stocks and caused the appearance of females in the hybrid populations.

(*vi*) To increase the number of genetic groups that may be tested in a limited number of ponds. The number of ponds available for genetic experiments and breeding programmes is the most serious limiting factor in most aquaculture research stations. In the absence of effective markers only one genetic group may be spawned in one pond. However, with genetically marked stocks, several groups can be spawned and nursed simultaneously in the same pond (Moav *et al*, 1976a).

(*vii*) To enable the production of identifiable full- and half-sib offspring from the same set of parents (Brody *et al*, 1976). Analysis of variation among such familial groups is essential for partitioning genetic components of quantitative characters, for progeny testing and for family selection. For example, even a single polymorphic electrophoretic locus with two alleles A_1 and A_2 enables a simultaneous mating of a single homozygous female, say A_1A_1, with the two homozygous males (A_1A_1 and A_2A_2). All the offspring of the first father would be A_1A_1 and those of the second father A_1A_2. With more than one locus, more complicated mating schemes can be made and more genetic information gained.

5.1 *Morphological markers*

Morphological markers, such as genes for colour and scale pattern, are the easiest to identify—an important advantage when large samples are required. Their disadvantages are: (*i*) as a rule, heterozygous individuals cannot be identified because of complete dominance; (*ii*) frequently these markers are associated with deleterious pleiotropic effects on viability, growth rate, *etc*, and (*iii*) the morphological expression of some of these markers has marketing disadvantages.

Soviet geneticists have used scale pattern and body colouration mutants in several genetic investigations of carp. Some colour mutants were introgressed from the Japanese ornamental carp (Katasonov, 1974). In the USA various odd-coloured lobsters were bred in order to serve as natural tags for growth rate studies (Hughes, 1968). In the bullfrog (*Rana catesbiana*) the discovery of skin markings that may be used as fingerprints for individual identification has facilitated genetic research (Nace, 1968; Culley and Gravois, 1969). A combination of scale pattern and colour mutants enabled the design and conduct of rather complex experiments in which the effect of maternal age, relative hatching time and stocking density on growth rate were partitioned (Wohlfarth and Moav, 1970; Hulata, Moav and Wohlfarth, 1976).

Colour mutants, such as albino trout and catfish, and gold carp, have a special application for sport fishing.

5.2 *Blood group antigens*

Serological reactions make it possible to reveal in fish polymorphic blood groups similar to those of man. Such groups have been reported in more than 50 species of freshwater and marine fishes (Kirpichnikov, 1973a) and they could be used as genetic markers. Their great potential advantage (over electrophoretic markers) is the relative ease of genotype identification by simple techniques that can be carried out right on the pond banks. They share with morphological markers the same disadvantage that frequently heterozygous individuals cannot be identified. Furthermore, the study and application of this technique is still hindered by technological problems, such as difficulty in producing large quantities of specific high-titered antisera, and by theoretical problems, such as relating blood groups to genes (Utter, Hodgins and Allendorf, 1974).

5.3 *Electrophoretic markers*

This group of markers is by far the most important for the breeder and for the population biologist (Utter, Hodgins and Allendorf, 1974; Kirpichnikov, 1973a; Reichenbach-Klinke, 1973; Christiansen, Frydenberg and Simonsen, 1973). Electrophoretic proteins controlled by different alleles of a single locus are, as a rule, co-dominant and therefore heterozygotes can be easily distinguished. Other advantages of electrophoretic markers are: (*i*) the relative abundance of polymorphic loci and the relative ease of developing procedures for identification of new protein systems; and (*ii*) the relative selective neutrality of most electrophoretic variants.

It might be stressed that previous studies in fish genetics have shown that genetic investigation of fish beyond the preliminary phases should not be undertaken without the aid of good biochemical markers.

6 Gynogenesis, polyploidy and mutagenesis

Chromosomal manipulations and artificial induction of mutations have long been established as highly advantageous in plant breeding. It is very likely that they will be just as efficient in fish. The fish breeder, unlike the breeder of farm animals, can handle both male and female gametes outside the organisms and has manipulative control over the developing zygote. Supported by recent experimental results, it is safe to predict that in the not too distant future these techniques will play a major role in fish breeding.

6.1 *Gynogenesis*

Gynogenesis is a special case of reproduction where the sperm head has to penetrate the ovum to induce embryo development from an exclusively maternal nucleus. This type of reproduction was found and studied in nature in two unrelated fish species, in the Central American live-bearing *Mollienesia formosa* (Hubbs and Hubbs, 1946; Kallman, 1962), and in *Carassius auratus* whose range of natural distribution extends from Japan and China to West Europe (Tcherfas, 1971). In both cases the gynogenetic offsprings have genotypes identical to their mother, *ie*, this process leads to the reproduction of the exact maternal genotype in an unlimited succession of generations. The great advantage to the fish breeder of such a reproductive mode is that it constitutes a *de facto* vegetative reproduction that can maintain and multiply a single genotype regardless of its level of heterozygosity. A second potential advantage is that gynogenetically reproducing populations tend to have only the female sex. In some cases of mating between distantly related species, the sperm occasionally induces gynogenetic reproduction. This provides means of selecting females with higher genetic tendency for gynogenesis (Tcherfas, 1971).

The technique of artificial gynogenesis is based on inactivation of sperm by irradiation, and diploidization of the female chromosome set by a cold shock (Purdom and Lincoln, 1973). Soviet scientists employed this method successfully on carp (*Cyprinus carpio*), sturgeon (*Acipenser ruthenus*) and loach (*Misgurnus fossilis*) (Golovinskaya, 1968; Golobinskaya, Cherfas and Tsvetkova, 1974). Unlike natural gynogenesis, under artificial gynogenesis the embryo is developed from the reduced postmiosis I-nuclei. Consequently, the gynogenetic offspring are highly homozygotic, 50–100%, depending on the stage at which diploidization took place (Purdom, 1969). The production of inbred lines by the conventional sexual reproduction requires up to 20 generations of inbreeding. Gynogenesis should supply the fish breeders with almost instantaneous inbreds that could be tested for heterotic F_1 combinations.

6.2 *Polyploidy*

Cold-shocking diploid eggs and zygotes may produce autopolyploid offspring that should be sterile with all the commercial advantages of sterility mentioned earlier. Theoretically, triploids and tetraploids may grow faster than diploids under protected conditions. However, although polyploidization of plants has been widely applied for over 40 years, its contribution to improved commercial plant breeds (except for ornamentals) is very limited. In the Fisheries Laboratory, Lowestoft, UK, triploid plaice were produced by applying a cold shock to eggs after fertilization (Purdom, 1972). The sex ratio was undisturbed but both sexes were sterile. Similar attempts are under way with trout, and recently triploid *Tilapia aurea* were produced in the USA (Valenti, 1975).

It is interesting that the naturally occurring gynogenetic females of *Carassius auratus* var. *gibelio* are fertile triploids (Tcherfas, 1971).

The chromosomal constitution of many fish groups and other aquaculture organisms have been reported, including: oysters (Stiles and Longwell, 1973); plaice (Purdom, 1972); salmonids (Svardson, 1945; Grammeltvedt, 1975); sunfishes (Roberts, 1964); sturgeons (Nikoljukin, 1971); cyprinids (Ohno, Wolf and Atkin, 1968). Chromosomal counts and related cytological studies are, as a rule, prerequisites to more sophisticated chromosomal manipulations of potential interest to the breeder.

6.3 *Mutagenesis and mutation breeding*

Mutagenesis describes the artificial induction of mutations by irradiation and chemical mutagens, while the use of artificially-induced mutations in breeding is called mutation breeding. In the last 15 years the role of mutation breeding in the genetic improvement of plant crops has been rapidly increasing (Gustafsson, 1969; Swaminathan, 1969; Favert, 1973). Its main contribution is the substitution of single alleles by more desirable ones when the latter could not be found in available gene pools or in the absence of practical means of incorporating superior alleles from outside sources into commercial varieties.

Basic research in radiation genetics of fish is quite extensive (Schröder, 1973). However, the presence of a vast unexplored natural variability in practically all aquaculture organisms indicates that mutation breeding, with the exception of specific objectives such as sex reversal (Schröder, 1973; Schultz, 1973; Yamamoto and Onitake, 1975), induction of gynogenesis and production of genetic markers would play only a minor role in aquaculture genetic improvement in the near future.

7 Future needs in genetic research

Genetic research, particularly its applied aspects related to aquaculture organisms, is lagging far behind that of crop plants and farm animals. Even in aquaculture-conscious Japan, of the 944 Japanese geneticists registered in the directory of the Twelfth International Congress of Genetics, Tokyo, 1968, only four were cited as involved in fisheries research—one works with pearls, two on sexuality of fish and one on invertebrate sex determination (Longwell, 1973). In view of the present worldwide importance of aquaculture and its even greater future potential, this situation is intolerable. Some reasons for aquacultural genetic lag were given by the *ad hoc* Working Party on Genetic Selection and the Conservation of Genetic Resources (FAO, 1972). The report of this group listed high-priority problems for genetics research as applied to aquaculture. With some alterations, these are:

(*i*) Systematic exploration and testing of wild genetic stocks to supplement or substitute current cultivated strains that might have been chosen from the wild by chance.

(*ii*) Initiation of genetic studies of production characters in aquaculture organisms in order to broaden our knowledge base, required for designing efficient breeding projects.

(*iii*) Establishment of genetically sound and properly

controlled breeding projects for the major aquaculture species. Present knowledge strongly indicates that relatively simple steps may result in large-scale genetic improvement of commercial breeding stocks. Thus, cross-breeding of current breeds is likely to result in heterosis, and substitution of local by proven non-indigenous genetic stocks may sometimes result in considerable improvements.

(*iv*) Frequently, the limitation on carrying out genetic experiments is the lack of sufficient facilities, mainly experimental ponds. Therefore, the establishment of more facilities is urgently needed. It may be noted at this point that we have succeeded in partially alleviating this shortcoming by integrating genetic tests with husbandry experiments comparing various formulae of polyculture, feeding, aeration, *etc.* An added advantage of this integration has been that substantial information on genotype × husbandry systems interactions has been obtained.

(*v*) Culture in stagnant or recirculating water systems exposes cultured organisms to contamination by toxic metabolites. Therefore, basic research on the physiological nature and genetic basis of these metabolites is of primary importance.

(*vi*) Successful transfer from traditional, low-input aquaculture to high-input intensive culture would be facilitated if accompanied by a parallel genetic change (Moav, Hulata and Wohlfarth, 1975; Moav *et al*, 1976).

(*vii*) High yields require, as a rule, high stocking densities, but high densities increase the severity of disease and parasite infestations. Breeding of resistant strains should contribute appreciably to the solution of these problems.

(*viii*) Interspecific hybridization should be expanded and directed toward synthesizing new breeds that are better adapted to new culture systems and for the production of sterile and monosex hybrids.

(*ix*) Culture of homing fish that pasture in the open seas and come back to their home farms is the most efficient way of harvesting the fish-food resources of the oceans. Selective breeding should contribute greatly to extending the use of these fish.

(*x*) Basic cytogenetic work on chromosomal manipulations and mutagenesis should be expanded.

(*xi*) The genetic control of many polymorphic electrophoretic and blood group antigen markers should be worked out in all the major groups of aquaculture organisms.

(*xii*) Immediate action should be taken to conserve endangered genetic resources of aquaculture.

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Variation in Growth Rate and Age at Sexual Maturity in Rainbow Trout

D. Møller, G. Naevdal, M. Holm and R. Lerøy

Abstract

Selective breeding experiments with salmonids in Norway have started to produce breeding stock better adapted to fish farming than the material now in use. Two desirable significant improvements for rainbow trout (*Salmo gairdneri*) breeding stock are a higher mean growth rate and higher mean age at first maturation. Sexual maturity at an early age or at a small size is a serious drawback for production of large rainbow trout because maturation retards the growth rate of the fish, and some fish farmers claim that it causes increased mortality.

Experiments with respect to these characters were carried out in Norway with the following results:

(*i*) Considerable differences were found between sib groups of rainbow trout in the proportion of fish maturing in their second and third years.

(*ii*) No relationship was found between growth rate and age at maturity within groups in their second year of life; while in most groups, maturing fish in their third year were found to have 1–3 cm higher mean length than immature fish.

(*iii*) Correlation between mean growth rate of the groups and proportion of fish maturing in their second and third years was uncertain, and in most cases insignificant.

(*iv*) Based on calculation of half sib and full sib correlations, both non-additive and additive genetic factors seem to play a role for mean age at first maturation. For proportions of fish maturing in their second year, only non-additive factors were found to be of importance.

(*v*) Mean growth rate, measured as length and weight variation, was found to vary considerably between sib groups, and at least part of this variation seems to be controlled by additive genetic factors.

(*vi*) Correlation of mean growth rate at different ages was found to be high within one year, but rather low between measurements taken at broader time intervals.

Variation du taux de croissance et de l'âge à la maturité sexuelle chez la truite arc-en-ciel

Résumé

Des expériences d'amélioration génetique portant sur des salmonidés norvégiens ont commencé à produire un stock de reproducteurs mieux adapté à la pisciculture que le matériel utilisé actuellement. On cite notamment deux améliorations significatives du stock de reproducteurs de truites arc-en-ciel (*Salmo gairdneri*): un taux moyen de croissance plus élevé et une moyenne d'âge superieure à la première maturation. La maturité sexuelle à un âge précoce ou à une petite taille est un grave inconvénient pour la production de grosses truites arc-en-ciel, car la maturation retarde le taux de croissance du poisson et certains pisciculteurs affirment qu'elle provoque une mortalité accrue.

Des expériences relatives à ces deux caracteristiques ont donné les résultats suivants en Norvège:

(*i*) On a trouvé des écarts considérables entre des groupes sib de truites arc-en-ciel en ce qui concerne la proportion des poissons arrivant à leur maturité à leur seconde et à leur troisième année.

(*ii*) L'on n'a pas trouvé de rapport entre le taux de croissance et l'âge à la maturité au sein des groupes pour les poissons parvenant à cette maturité lors de leur seconde année, alors que dans la plupart des groupes les poissons arrivant à la maturité dans leur troisième année ont accusé une longueur moyenne supérieure de 1 à 3 cm à celle des poissons immatures.

(*iii*) La corrélation entre le taux de croissance moyen des groupes et la proportion des poissons arrivant à la maturité dans leur deuxième et dans leur troisième année était incertaine, et dans la plupart des cas insignifiante.

(*iv*) Sur la base du calcul des corrélations des demi-frères et des frères, les facteurs génétiques tant cumulatifs que non cumulatifs semblent jouer un rôle pour l'âge moyen à la première maturation. Pour les proportions de poissons atteignant la maturité dans leur deuxième année, on a trouvé que seuls les facteurs non cumulatifs sont importants.

(*v*) On a constaté que le taux de croissance moyen, mesuré comme variation de la longueur et du poids, diffère considerablement entre groupes sib, cette variation semblant dépendre, du moins en partie, de facteurs génétiques cumulatifs.

(*vi*) L'on a constate que la corrélation du taux de croissance moyen à des âges différents était forte au sein d'une année, mais assez faible pour les mesures obtenues à des intervalles de temps plus espacés.

Variación de la tasa de crecimiento y de la edad en el momento de la madurez sexual en la trucha arco iris

Extracto

En experimentos de cria selectiva de salmónidos en Noruega se han empezado a producir cepas de reproductores mejor adaptadas a la piscicultura que el material actualmente utilizado. Dos mejoras importantes que son deseables en las cepas de reproductores de trucha arco iris (*Salmo gairdneri*) son el aumento de la tasa media de crecimiento y el aumento de la edad media en el momento de la primera maduracion. La madurez sexual a edad temprana o con una talla pequeña constituye un serio inconveniente para la producción de trucha arco iris de gran talla, ya que la maduracion afecta la tasa de crecimiento del pez y algunos piscicultores alegan incluso que determina un aumento de la mortalidad.

Se han realizado experimentos en Noruega sobre estos factores, con los siguientes resultados.

(*i*) Se han encontrado considerables diferencias, entre grupos de parientes de trucha arco iris, en el porcentaje de peces que maduran en el segundo y tercer año.

(*ii*) No se encontró ninguna relación entre la tasa de crecimiento y la edad en el momento de la madurez en los grupos en su segundo año de vida; en cambio, en la mayoría de los grupos se encontro que la longitud media de los peces que maduran en su tercer año era superior en 1–3 cm a la de los peces inmaduros

(*iii*) La correlación entre la tasa media de crecimiento de los grupos y el porcentaje de los peces que maduran en el segundo y tercer año resultó incierta y, en la mayor parte de los casos, insignificante.

(*iv*) Sobre la base del cálculo de las correlaciones entre medio parientes y parientes completos, parece que, por lo que se refiere a la edad media en el momento de la primera maduración, intervienen tanto factores genéticos no aditivos como aditivos. Por lo que se refiere al porcentaje de peces que maduran en el segundo año, sólo resultaron importantes factores no aditivos.

(*v*) Se encontró que la tasa media de crecimiento, medida como variacion de la talla y el peso, varia considerablemente entre grupos de hermanos, y al menos parte de esa variación parece deberse a factores genéticos aditivos.

(*vi*) La correlación de la tasa media de crecimiento a diversas edades resultó elevada en el ámbito de un año, pero relativamente baja haciendo las mediciones a intervalos de tiempo más largos.

1 Introduction

For the last twenty years farming of rainbow trout (*Salmo gairdneri*) has been of a growing interest in Norway. Most fish farmers now produce fish of an individual weight of over 1·5 kg, often reaching 3–4 kg.

Sexual maturity at an early age or at a small size is a serious drawback in the production of large rainbow trout because maturation retards the growth rate, and some fish farmers claim that it causes increased mortality.

Several characteristics of the rainbow trout, including growth rate and mean age at maturity, have been altered by selection (Savost'yanova, 1969). In Norway, selective

breeding experiments with salmonids have started to produce breeding stock which is better adapted to fish farming than the material now in use. For the rainbow trout, significant improvements are a higher mean growth rate and higher mean age at first maturation. Variations in these characters are described in the present report, and tentative calculations of heritability factors are given.

2 Material and methods

Egg and milt material for the present experiments were obtained from a commercial Norwegian fish farm, Eros Laks, N-5627 Bjordal, in the winter of 1972/73. In 1973, milt from three males from another fish farm, Bolstad Fiskeanlegg, N-5972 Holdhus, was included.

The rainbow trout at Eros Laks came originally from Denmark. Through two or three generations mass selection for high growth rate and higher age at first maturation had been carried out by the owner of the fish farm, but due to lack of unselected material for control, the effect of the selection is unknown.

The present experiments are based on sib groups. The egg portion of each female was divided into two equal parts and fertilized with milt from two different males. Each male was normally used for two females. For various reasons, this 2 × 2 pattern of combinations was only partly followed in 1973.

The eggs were hatched at the hatchery of the research station Fisk og Forsøk, N-5198 Matredal. From start of feeding to an age of 16 months (1972 year-class) or 8 months (1973 year-class) the fish were kept in floating cages in brackish water until being transferred to sea water. The 1972 year-class went to a shore enclosure at Eros Laks, and the 1973 year-class to 50 m^3 floating cages kept at the commercial fish farm Risnefisk, N-5950 Brekke.

During their first months of life, each group was kept in a separate tank. From about six months of age they were marked with combinations of fin clipping (adipose fin or pelvic fins), and some of the fish were also tagged with Floy Tags (FT4 Spaghetti Tag, FT4 Lock-on, FT6 Dart Tag or FD67C, all from Floy Tag and Mfg., Inc., Seattle, Washington, USA).

Some of the sib groups died out during the egg and dry stages. The main causes were accidental (mostly technical problems with water supply), and in part an outbreak of vibriosis. Unfortunately, these accidents extinguished 1–2 groups from almost all the 2 × 2 sets, therefore, only 6–8 groups could be used for calculating heritability factors.

The lengths of 100 or 200 fish of each group were recorded every six months. Individual weights were recorded at 30 months for the 1972 year-class, and at 24 and 30 months for the 1973 year-class. Sexual maturity was recorded in the autumn and spring of the second year of life and in the autumn of the third year. At 30 months of age, most of the fish were slaughtered, while 20–30 individuals of each group were kept alive for the F_2 generation.

3 Results and discussion

3.1 *Relation between sexual maturity and growth*

An account of mean lengths of groups of maturing, mature and immature fish is given in Table I. Fish of the 1973 year-class (mostly males) maturing in their second year of life could be recognized early in November 1974. The material is scanty in most groups, but the mean length of maturing and immature fish are similar, indicating that at this time there is no relationship between maturity and growth rate. Whether or not a fish will mature in its second year under given environmental conditions seems to be unrelated to its size, and until 2–3 months before normal spawning time maturity does not seem to affect growth.

In the spring, mature fish of nearly all groups of both year-classes showed significantly lower mean lengths than did the immature fish, showing that maturation caused retarded growth rate during the spawning season.

The proportions of mature fish in the groups were found

TABLE I

MEAN LENGTH (IN CM) OF MATURING, MATURE AND IMMATURE RAINBOW TROUT (NUMBERS IN BRACKETS)

1972 Year-class

Age in months		*Sib group no.* 1	5	6	7	8	9	12	13	14	15	16	17	18	19	20	21
Jun. 1974	Mature	34·2	34·6	35 1	33 6	35·7	35 2	31·3	33 1	35·0	31·9	34·3	31 0	40·5	36 1	37 1	36·5
26 months		(17)	(20)	(43)	(26)	(14)	(9)	(7)	(5)	(1)	(13)	(6)	(6)	(1)	(8)	(4)	(12)
	Immature	37·2	37·8	37·6	35·9	36·8	36·4	34·7	36·1	36·1	38·3	37·4	37·4	38·9	40·1	38·6	38·1
		(157)	(108)	(107)	(100)	(93)	(131)	(84)	(110)	(64)	(85)	(93)	(105)	(61)	(101)	(107)	(72)
Oct. 1974	Maturing	53 6	48·9	51·4	47·9	47·0	47 3	49·5	49·0	50·1	48·8	50·3	51·2	55·3	52·7	53·4	48·4
30 months		(14)	(22)	(63)	(39)	(11)	(13)	(19)	(9)	(4)	(14)	(18)	(10)	(12)	(19)	(27)	(20)
	Immature	51·1	47 5	48·0	48·2	48·7	47·8	46·4	49·3	48·9	49·8	47·6	49·8	51 1	47·0	47·9	49 2
		(119)	(28)	(76)	(47)	(47)	(93)	(112)	(38)	(12)	(16)	(10)	(31)	(12)	(15)	(18)	(15)

1973 Year-class

Age in months		*Sib group no.* 22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37
Nov. 1974	Maturing	–	33·6	32·0	31·0	36·5	–	—	–	34·6	36·9	33 9	31·0	—	34·0	34·8	32·5
20 months			(6)	(1)	(2)	(1)				(36)	(4)	(8)	(1)		(1)	(14)	(2)
	Immature	36·5	33·2	34·0	33·9	34·0	35·5	30·0	33·9	36·4	36·0	34 6	34·9	34·9	35·8	34·6	33·1
		(100)	(101)	(101)	(101)	(103)	(100)	(100)	(101)	(64)	(86)	(99)	(101)	(111)	(117)	(103)	(100)
Apr. 1975	Mature	39·8	35·1	38·0	34·9	34·7	34·0	32·0	—	36·2	37·2	34·1	—	39·0	38·0	37·8	33·4
24 months		(4)	(7)	(1)	(8)	(3)	(1)	(1)		(54)	(11)	(22)		(1)	(1)	(16)	(5)
	Immature	43·2	38·3	41·2	40·5	40·0	41·9	35·2	40·3	43·4	43·4	42·1	41·9	41·3	43·3	42·3	39·7
		(121)	(116)	(124)	(117)	(122)	(124)	(122)	(125)	(68)	(114)	(103)	(125)	(124)	(124)	(109)	(120)
Oct. 1975	Maturing	55·0	50·5	53·1	52·7	52·7	53·4	46·0	53·0	50·3	53·3	52·1	53·4	53·3	55·5	53·3	51·4
30 months		(29)	(24)	(77)	(37)	(30)	(34)	(6)	(13)	(93)	(73)	(74)	(47)	(28)	(41)	(72)	(71)
	Immature	53·2	47·9	50·5	50·9	50·2	50·4	46·1	51·2	48·5	50·3	48·8	51·7	51·4	53·6	50·0	47·9
		(50)	(55)	(15)	(67)	(64)	(50)	(86)	(86)	(2)	(11)	(14)	(43)	(54)	(37)	(10)	(20)

to be nearly the same in November 1974 as in April 1975 for the 1973 year-class, indicating that maturation had caused no significant increase in mortality during winter. In April 1975, 125 fish of each group were individually tagged, with mature fish occurring among the tagged ones in approximately the same proportions as in the whole groups. When observed again in October 1975, fish which had been mature in their second year of life were found to survive nearly as well as the immature fish. The former had approximately 8% lower survival rate during the spring and summer than the latter. This is to some extent in contrast to the experience of fish farmers who claimed that mature fish show markedly increased mortality during early spring.

All controlled fish which had been mature in their second year, except for three males, were maturing again in their third year.

Table I shows mean length for immature fish and those maturing in their third year (October 1974 and 1975). In most groups the mean length for maturing fish was found to be 1–3 cm higher than for immature fish. Thus, maturation in the third year of the fish's life seems to be partly dependent on individual growth rates within sib groups.

Correlation factors between proportions of mature individuals (transformed to $\sin^{-1}\sqrt{}$ % mature) and mean length of groups in the autumn prior to the spawning season were calculated in order to study the relation between age at maturation and mean growth rate of the sib groups. Concerning maturity in their third year, a correlation factor of 0·52 ($0{\cdot}2<P<0{\cdot}5$) was found for the 1972 year-class, while corresponding correlations for the 1973 year-class and for both year-classes concerning maturity in the second year were insignificant. This implies that mean growth rate of the groups is of little, if any, importance for age at maturation.

3.2 *Heredity and age at maturity*

Table I shows that considerable variations were observed in proportions of mature individuals in their second and third years in the different groups. The environment was kept the same, as well as could be managed for practical reasons, for all groups within the year-classes, and therefore it is reasonable to conclude that genetic factors must be responsible for part of the variation.

Donaldson (1959) altered the age of maturity of female rainbow trout by selective breeding. This implies that additive genetic factors control this trait. To estimate heritability factors in the present investigation, a nested design of analysis of variance was applied, utilizing correlations between half sib groups (Becker, 1967) and using the corrections for percent data calculated from unequal subclass numbers by Bogyo and Becker (1965). The percent data were transformed to $\sin^{-1}\sqrt{}$ % mature before calculations.

Concerning maturation in their second year of life, calculated heritability factors (h^2) from paternal (S) and maternal (D) half sib groups were rather low:

1972 year-class: $h^2_S \sim 0{\cdot}09$ $\quad h^2_D \sim 0{\cdot}01$

1973 year-class: $h^2_S \sim 0{\cdot}0$

In their third year of life, however, high heritability factors, 0·47 and 0·74 for the 1972 and 1973 year-classes respectively, were calculated based on paternal half sibs, while based on maternal half sibs (1972 year-class only) a factor near zero was found. Heritability factors calculated from full sib groups within sets of half sibs were generally high; in the order of 0·4–0·5.

Due to the rather low number of groups, the confidence limits are rather wide for the estimated heritability factors, so the present results have to be confirmed by further studies. Judging from the low estimates of heritability factors based on half sib groups that were found in the fish's second year, additive genetic factors seem to be of little importance for early maturity of rainbow trout. However, the rather high factors calculated for maturity in the third year seem to point in the opposite direction. The rather high estimates of heritability factors based on full sib groups indicate that non-additive genetic factors could be of importance for age at maturity as such estimates include part of the dominant gene effect (Becker, 1967). If this is confirmed by study of more extensive material, the best results of a genetic improvement programme would be reached by hybridization of pure lines. However, genetic improvement may be obtained by selective breeding even if the heritability is low, because of the high selection intensity which may be applied on fish.

3.3 *Heredity and growth rate*

Mean lengths and weights, reflecting mean growth rate, for each group at different ages are shown in Table II. Great variations were observed among the groups, corresponding to the variations in mean age at first maturity. Therefore, it is reasonable to conclude here that part of the variations are genetically controlled.

Heritability factors were calculated using a factorial design (1972 year-class) and a nested design (both year-classes) as described by Becker (1967). The calculated estimates varied considerably according to the method of calculation (the same groups could not be used in all analyses) and also the age of the fish. Calculated from half sib groups, most estimates were in the range 0·0–0·3, but calculated from full sib groups, estimated heritability factors were usually in the order of 0·25–0·50 and even higher. Generally, variation between groups was higher at younger ages, and thus calculated heritability factors, especially when calculated from full sib correlations, were also higher. The reason may be that unknown systematic environmental variation had a greater effect on the early stages when the groups were kept in separate trays or tanks. Although the environment was kept as similar as possible in all tanks, 'tank-effect' as found among others by Aulstad, Gjedrem and Skjervold (1972) may be responsible for part of the observed variations.

Estimates of heritability factors of weight variation were usually higher than corresponding estimates for length, indicating that body shape (weight/length ratio) also shows variation, probably controlled by additive genetic factors.

Variations in proportions of fish maturing in their second year will have an influence on the variations in growth rate at 24 and 30 months (see Table I) because maturity retards growth rate. Variations in total growth rate may, therefore, be the combined effect of factors controlling growth rate and age at first maturity.

Aulstad, Gjedrem and Skjervold (1972) estimated heritability factors for length in the range 0·18–0·50 for full sib groups of young rainbow trout, and in the range 0·01–0·37 for length and weight based on half sib correlations. Most estimates from the present study fell within the range of

their calculations, but some considerably higher estimates were also obtained.

The confidence limits were rather wide for the estimated heritability factors, reflecting the scarcity of the material for most of the calculations. However, in spite of this limitation, the results so far indicate that additive genetic factors are of importance to the growth rate of rainbow trout, implying that selection would be effective for genetic improvement. Non-additive genetic factors seem also to be involved, indicating that hybridization of pure lines could be useful. This conclusion is supported by the fact that significant sire × dam interactions were observed in some calculations using the factorial design. Experiments are now being undertaken to test the effect of both methods.

To compare the variation in growth rate at different ages between groups, correlation and regression coefficients were calculated between mean lengths for each group at different ages. The calculated coefficients are presented in Tables III and IV which show that correlation is high for observations taken within 6 or 12 months, but rather low for those taken at broader time intervals. Accordingly, selection for high growth rate should preferably be made at 30 months (normal age for slaughtering), and yet selection after one summer in sea water (18 months of age) or one year in sea water (24 months) could also be effective. Selection for high growth rate in the first year of life seems to be of little value for improvement of growth rate in the sea but could be valuable for shortening the expensive freshwater stage as tolerance of sea water is highly correlated with size.

TABLE III

CORRELATION COEFFICIENTS (ABOVE DIAGONAL) AND COEFFICIENTS OF REGRESSION (BELOW DIAGONAL) OF MEAN LENGTH OF SIB GROUPS OF RAINBOW TROUT HATCHED IN 1972 AND MEASURED AT FIVE DIFFERENT AGES

Age (in months)	*6*	*12*	*18*	*24*	*30*
6	—	0·81	0·67	0·48	0·06
12	1·47	—	0·40	0·25	−0·18
18	1·60	0·55	—	0·79	0·63
24	0·74	0·22	0·50	—	0·74
30	0·16	−0·26	0·61	1·14	--

TABLE IV

CORRELATION COEFFICIENTS (ABOVE DIAGONAL) AND COEFFICIENTS OF REGRESSION (BELOW DIAGONAL) OF MEAN LENGTH OF SIB GROUPS OF RAINBOW TROUT HATCHED IN 1973 AND MEASURED AT FIVE DIFFERENT AGES

Age (in months)	*6*	*12*	*18*	*24*	*30*
6	-	0·90	0·64	0·51	0·49
12	1·22	—	0 65	0·59	0·59
18	0·66	0·51	—	0·89	0·83
24	0·75	0·64	1·26	--	0·92
30	0·67	0·61	1 10	0·86	—

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TABLE II

DATA ON GROWTH RATE AND MATURATION OF SIB GROUPS OF RAINBOW TROUT

Group no.	*6 months mean length mm*	*12 months mean length mm*	*18 months mean length cm*	*24 months*		*30 months*	
				mean length cm	*mean weight g*	*mean length cm*	*mean weight g*
1972 Year-class							
01	97·5	170·6	27·25	37·22		50·60	1 470
03	121·7	201·2	30·93				
05	111·8	188·2	28·35	37·79		47 98	1 300
06	115·9	195·0	29 37	37·59		49·16	
07	107·2	181 4	27·30	35·92		47 90	1 370
08	116·0	201·0	29·73	36·76		47·61	1 250
09	117·2	197·8	29 58	36·42		47·53	1 200
12	102·5	169·3	25 46	34·73		46·30	1 120
13	107·4	167·3	28·95	36·10		49·55	1 620
14	103·3	162 3	28·56	36·13		50·02	1 580
15	104·8	179·3	31·29	38·30		50·99	2 040
16	100·0	164·6	29 80	37·37		50·98	2 050
17	112·2	168·1	29·69	37·44		50·52	1 900
18	108·6	170·3	30 32	38·88		53 97	1 920
19	127·9	195·9	33·44	40·09		52·02	2 020
20	116·3	202·0	32·09	36·10		51·71	2 324
21	—	172 3	32·40	38·13		50·12	1 640
1973 Year-class							
22	124·7	192·2	36·51	43·12	1 144	53·84	2 222
23	111·3	164·5	33·50	38·09	877	48·75	1 722
24	109·8	184·4	34·00	40·70	985	52·82	2 279
25	119·8	197·1	33·84	40·20	882	51·79	2 005
26	111·0	162·2	34·01	39·81	933	51·13	1 884
27	113·6	176·7	35·49	43·74	1 161	51·74	2 011
28	90·6	137·6	30·01	35·19	629	46·30	1 357
29	98·9	150·8	33·92	40·30	1 052	51·40	2 012
30	138·3	195·4	35·73	39·86	950	50·41	1 954
31	141·1	209·7	35·99	42·70	1 224	53·02	2 318
32	134·4	188·5	34·57	40·97	1 024	51·66	2 039
33	137·5	208·1	34·88	41·88	1 013	52·73	2 151
34	117·1	182·2	34·87	41·35	974	52·26	2 036
35	115·9	171·0	35·82	43·30	1 203	54·96	2 414
36	135·9	190·6	34·63	42·02	1 064	52·97	2 100
37	126·5	186·1	33·11	39·42	915	50·73	2 014

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Comparisons of Growth and Survival of Channel Catfish, *Ictalurus punctatus*, from Distinct Populations

O. L. Green, R. O. Smitherman and G. B. Pardue

Abstract
Eight groups of channel catfish were evaluated for growth rate and survival in aquaria, cages within a pond, and ponds The groups were progenies of stocks from four unselected riverine populations, two domesticated populations, and crossbred progenies between a domesticated stock and two unselected riverine populations. Significant differences ($P<0.05$) in growth rate and survival were found among the weight groups. The greatest growth rate in all tests was exhibited by a domesticated group which had been cultured for several generations. A relatively high rate of growth and greatest variability was observed in a wild riverine strain. The two crossbred groups ranked highest in overall survival.

Comparaisons entre les taux de croissance et de survie d'ictalures tachetés, *Ictalurus punctatus*, de populations diverses
Résumé
Les taux de croissance et de survie de huit groupes d'ictalures tachetés ont été evalués dans des aquariums, des cages (disposées dans un etang) et dans des etangs. Les groupes comportaient les descendances de stocks de quatre populations fluviales non sélectionnées, deux populations d'élevage, et les descendances croisées d'un stock d'élevage et de deux populations fluviales non sélectionnées. On a trouvé entre les huit groupes des différences notables (P 0,05) des taux de croissance et de survie. Pour l'ensemble des essais, le taux de croissance le plus elevé a été atteint par un groupe d'élevage soumis à la pisciculture depuis plusieurs générations. On a observé un taux de croissance relativement élevé et une variabilité plus grande dans les souches fluviales sauvages. Les deux groupes de descendance croisée atteignaient globalement les taux de survie les plus forts.

Comparaciones sobre el crecimiento y la supervivencia de bagre de canal, *Ictalurus punctatus*, de poblaciones diferentes
Extracto
Se evaluaron 8 grupos de bagres de canal para determinar su indice de crecimiento y su supervivencia en acuarios, jaulas colocadas dentro de un estanque, y estanques. Los grupos en cuestion eran descendientes de progenitores de cuatro poblaciones fluviales no seleccionadas, dos poblaciones domésticas, y cruces de una población doméstica y dos poblaciones fluviales no seleccionadas. Se encontraron notables diferencias (P 0.05) en la tasa de crecimiento y supervivencia entre los 8 grupos. En todos los ensayos, la tasa mayor de crecimiento se registró con un grupo doméstico, el cual se ha estado cultivando desde hacia varias generaciones. En un grupo de bagres fluviales criados libremente se registró la mayor variabilidad y una tasa de crecimiento relativamente alta. Los dos grupos de cruces alcanzaron la supervivencia total más alta

1 Introduction

Catfish farming in the United States has become a commercial reality. Annual production expanded from less than 45 tons in 1954 to 23 000 tons in 1974 (Aquatic Food Animal Task Force, 1975). This phenomenal growth is continuing despite many problems which plague the industry. Two important problems are rate and uniformity of growth in channel catfish (*Ictalurus punctatus*). Slow growing fish and fish of variable size often reduce profits to the commercial grower. These two problems are not unique to channel catfish as a large number of factors, environmental and genetic, contribute to rate and variability in growth in animal populations. In an effort to control these factors, research workers have provided improved environments and developed meaningful selection programmes with cattle, swine, and poultry. Selection of channel catfish for intensive culture has been largely a random process and stocks used do not produce predictable results.

The primary objective of this study was to evaluate different stocks of channel catfish to determine the potential for a selective breeding programme with this species.

2 Materials and methods

2.1 *Broodstock*

Several groups of channel catfish broodstock were collected from unselected river populations using traps, trot lines, electro-fishing, and gillnets. Other groups of channel catfish stock were obtained from hatcheries in the southern United States. Total numbers of individuals in a broodstock varied from 8 to 40. These groups were held in separate ponds until the time of spawning.

2.2 *Spawning*

Adult fish were sexed and pairs of individuals were placed in 95 l aquaria with running water. All females received injections of 1 100 IU of human chorionic gonadotrophin/kg of body weight every 48 hours until spawning occurred or the female aborted the eggs. This technique (Sneed and Clemens, 1960) permits obtaining all spawn during a short period of time.

During May 1971, eight different groups of catfish were spawned during a six day period. Four groups were first-generation offspring from 'wild' fish obtained from: the Kentucky River, Kentucky; Rio Grande River, Texas; Tennessee River, Kentucky; and Warrior River, Alabama. Two groups were offspring from domesticated stock of Marion National Fish Hatchery, Alabama and from the stock of a commercial farm at Yazoo City, Mississippi. Two groups were crossbred offspring from the Yazoo Hatchery broodstock and two wild river populations (Tennessee and Warrior).

2.3 *Nursing the young*

Groups of young catfish were held separately in $3 \times 0.36 \times 0.15$ m troughs with flowing water and fed a nutritionally complete, *ad lib* ration of floating fish feed (40% protein).

2.4 *Experiment in aquaria*

On 9 July random samples of fish of each group were stocked in 95 l aquaria with flowing water at the Southeastern Fishcultural Laboratory, Marion, Alabama. Fifty individuals (average length 45 mm and weight 1·3 g) of each group were placed in each of four replicate aquaria. The experiment had a duration of 98 days and all groups

received a nutritionally complete, *ad lib* ration containing 40% protein. These groups were weighed at two-week intervals until the experiment was terminated on 14 October.

2.5 *Experiment in ponds*

On 15 June random samples (average length 25 mm and weight 0·5 g) of each group were stocked into 0·04 ha earthen ponds at Auburn University Agricultural Experiment Station, Auburn, Alabama with three replications of 150 individuals (at a rate of 3 750/ha) each. The experiment had a duration of 147 days and all groups received a nutritionally complete, uniform ration of 40% protein feed at a minimum of 5% body weight daily. These groups were sampled by seine at two-month intervals to adjust feeding rates so that all groups were fed slightly in excess. The low stocking rate assured that there was also an abundance of natural foods until the termination of the experiment on 9 November.

2.6 *Experiment in cages*

On 29 July, 150 randomly taken fish (average length 55 mm and weight 1·5 g) of each group were stocked in four replicated cages (1 m^3) in a 0·5 ha earthen pond at Auburn University. The experiment had a duration of 83 days and all groups received a nutritionally complete, *ad lib* ration containing 40% protein. The groups were weighed at monthly intervals to adjust rates of feeding to excess of that required for the fastest growing fish. The experiment was terminated on 18 November.

3 Results

3.1 *Experiment in aquaria*

The results, summarized in Table I, show significant differences in net weight production among the tested groups. The Marion group grew faster than other groups. These fish were from stock that had been under intensive culture in ponds for approximately 20 years, whereas all other except the Yazoo River groups (cultured approximately five years) were recently removed from unselected river populations. Of the unselected river populations, the Rio Grande River fish grew at a greater rate than other tested river populations. Hybrid groups tended to be intermediate in rate of growth between their parental groups.

An examination of the ranges in weight of the eight groups grown in aquaria revealed that the Rio Grande group had the widest range in individual weight, followed by the Marion and Yazoo groups.

It appears from this experiment that selection for increased growth rate may have been effective in the Marion group with a fairly long history of culture, as compared to groups taken directly from the wild. Furthermore, there was tremendous variation in the performance of wild groups and the Rio Grande group grew at rates significantly ($P<0·05$) better than any but the Marion group in aquaria.

Average survival for the eight groups varied from 92·0 to 99·5% (Table II). There were significant differences in survival among the different groups; however, there were no clear indications that the wild stocks, hybrid crosses, or domesticated stocks were superior in survival.

3.2 *Experiment in ponds*

The results, summarized in Table I, show that the Marion group grew at a significantly ($P<0·05$) greater rate than all other groups except the crossbred Warrior × Yazoo. The growth of the crossbred Warrior × Yazoo was significantly ($P<0·05$) greater than either parental group, thus demonstrating heterosis. The growth of the other crossbred, Tennessee × Yazoo, was intermediate between its parents. Although complete history was unavailable on the Yazoo group, it is possible that up to two generations of inbreeding had occurred.

Again there were significant differences in the growth rates of wild river populations. In this experiment, the Rio Grande group performed better than the other wild groups.

There were no significant differences in survival rates among groups; however, mean survival rates were highest in the two crossbred populations.

TABLE I

MEAN NET YIELD (g) PER EXPERIMENTAL UNITS FOR EIGHT GROUPS OF CHANNEL CATFISH (6 STRAINS AND 2 CROSSBREDS) REARED IN AQUARIA, CAGES AND PONDS

Group	*Aquaria*		*Cages*		*Ponds*	
	Yield	*Rank*	*Yield*	*Rank*	*Yield*	*Rank*
Marion	779	1	2 686	1	19 733	1
Warrior × Yazoo	486	4	2 542	2	18 383	2
Rio Grande	600	2	2 271	5	14 779	3
Yazoo	554	3	2 418	4	13 961	4
Warrior	457	5	2 498	3	10 315	6
Kentucky	414	6	1 784	6	8 222	7
Tennessee	294	8	1 484	8	7 920	8
Tennessee × Yazoo	334	7	1 613	7	12 589	5

TABLE II

MEAN SURVIVAL (PERCENT) FOR 8 GROUPS OF CHANNEL CATFISH (6 STRAINS AND 2 CROSSBREDS) REARED IN AQUARIA, CAGES AND PONDS

Group	*Aquaria*	*Cages*	*Ponds*	*Combined*	*Rank*
Warrior × Yazoo	94·5	89 8	96·6	93·4	1
Tennessee × Yazoo	99·5	80·8	94·0	89·1	2
Warrior	91·5	81·3	91·8	87·3	3
Tennessee	95·5	78·7	92·4	87·0	4
Rio Grande	99·0	77·3	92·0	86·7	5
Marion	94·5	78·8	87·8	84·9	6
Yazoo	98·5	76·0	77·8	80·0	7
Kentucky	92·0	78·8	65·6	75·0	8

3.3 *Experiment in cages*

The results, as summarized in Table I, show considerable differences in growth rates among the tested groups, but loss of fish from several cages due to diseases or escapes made analysis for statistical significance meaningless. Based on group averages, however, the Marion fish again grew best, followed by the crossbred, Warrior x Yazoo. In the wild groups tested, the Rio Grande and Warrior were better in their growth performance than the Tennessee and Kentucky groups. There were no significant differences in survival among groups because of the large within-group variation. However, the two crossbreds both ranked in the top three in survival.

4 Summary and discussion

When the same eight stocks were grown in all three environments, the Marion group always had the best growth rate performance and the Tennessee group the worst. However, among other stocks there were changes in ranking in different environments. For instance, the Rio Grande stock has a lower ranking in cages than in either ponds or aquaria, whereas the opposite is true for the Warrior stock. This may be due to a specific adaptation of a stock to a particular environment.

Viability, expressed as percentage survival, varied considerably among the populations (Table II). On the basis of an overall ranking of mean survival, the two crossbreds ranked first and second, followed by three wild groups, and then the two domesticated lines. Heterosis is thereby indicated in viability, and it appears that viability has been reduced in the process of domestication of the two hatchery lines.

The results of these tests show the existence of variability in growth and viability among the eight stocks. Heterosis for both growth and viability was demonstrated in some cases. It seems likely that part of this variability is of genetic origin. In another test, the same stocks were compared for their resistance to channel catfish virus (Plumb *et al*, 1975). It was shown that the stocks varied markedly in this character, the highest resistance being shown by the two crossbreds. These results indicate that the channel catfish could be improved in characters of economic value by selective breeding.

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Selection of Common Carp (*Cyprinus carpio*) for Resistance to Dropsy

V. S. Kirpichnikov, K. A. Factorovich, Yu. I. Ilyasov and L. A. Shart

Abstract

Dropsy of common carp (*Cyprinus carpio*) causes serious damage in carp farms in Eastern Europe and the Soviet Union. Experiments on carp selection for resistance to dropsy were started in 1963 in the Krasnodar region (North Caucasus) of USSR and the results of the first ten years work have been published. This paper describes the work during 1973–75.

(*i*) The 5th generation of Ropsha carp strain (R) and the 3rd and 4th generations of local 'scattered' type carp (Ls) and Ukrainian-Ropsha hybrid carps (UR) were obtained and selected in an experimental plot in the Lower Kuban during 1973–75.

(*ii*) Males homozygous by the gene S (fully scaled fish) were detected in the strain UR (3rd generation). This permits elimination of segregation in this strain by scaly cover.

(*iii*) Selection of carp by their growth rate (in the first and partly in the second year) and by dropsy-resistance (in the second and third year) proceeded. Selection intensity (*i*) by weight gain was 1·5–2·0. Selection for resistance to dropsy was more moderate.

(*iv*) Experiments were performed on the infection of fish (1+ and 2+) by intraperitoneal injections of pathogenic material from the skin and viscera of diseased fish. In the course of tests, a dose was determined which was sufficient to induce disease in 50–80% of the injected fish.

(*v*) Two-year-old Ropsha carp of the 4th selection generation are more resistant to dropsy than non-selected control fish of the same strain. The difference in resistance is, however, not large.

(*vi*) Carp of all three hybrid combinations tested (Ls x R, Ls x UR and R x UR) exhibited heterosis by their growth rate and, in one case (Ls x UR) by viability.

Sélection de la carpe commune (*Cyprinus carpio*) pour sa résistance à l'hydropisie

Résumé

L'hydropisie de la carpe commune (*Cyprinus carpio*) cause de sérieux dégâts aux élevages en Europe orientale et en Union soviétique. Des expériences sur la sélection des carpes pour leur résistance à l'hydropisie ont débuté en 1963 en URSS dans la région de Krasnodar (Caucase septentrional), et les résultats des dix premières années de travail ont été publiés. Le document décrit les travaux effectués pendant la période 1973–75.

(*i*) On a obtenu et sélectionné pendant cette période dans une parcelle expérimentale du Kouban inférieur la cinquième génération de la lignée (R) de carpes Ropsha, et les troisième et quatrième générations de carpes du type local 'disséminé' (LS) et de carpes hybrides Ropsha-ukrainiennes (UR).

(*ii*) Des mâles homozygotes par le gène S (poisson totalement écailleux) ont été détectés dans la lignée UR (3e génération). Cela permet d'éliminer la ségregation imputable au couvert écailleux dans cette lignée

(*iii*) La sélection de carpes en fonction de leur taux de croissance (pendant la première année et en partie pendant la deuxième année) et de leur résistance à l'hydropisie (pendant les deuxième et troisième années) s'est poursuivie. L'intensité sélective (*i*) en gain pondéral a été de 1,5–2,0. La sélection pour la résistance à l'hydropisie a été plus modérée.

(*iv*) Des expériences ont porté sur l'infection des poissons (1+ et 2+) par injections intrapéritonéales de substance pathogène prélevée sur la peau et les viscères de poisson malade. Lors des tests, l'on a déterminé une dose suffisante pour transmettre la maladie à une proportion de 50 à 80% des poissons inoculés.

(*v*) Des carpes Ropsha de deux ans appartenant à la quatrième génération de sélection sont plus résistantes à l'hydropisie que des poissons témoins non sélectionnés de la même lignée. Toutefois, l'écart entre les résistances n'est pas considérable.

(*vi*) Des carpes des trois combinaisons hybrides soumises aux essais (Ls x R, Ls x UR et R x UR) ont manifesté une hétérosis exprimée par leur taux de croissance et, dans un cas (Ls x UR) par leur viabilité.

Selección de carpas comunes (*Cyprinus carpio*) para lograr resistencia a la hidropesía

Extracto

La hidropesía de la carpa común (*Cyprinus carpio*) causa graves daños en las granjas de carpa de Europa Oriental y la Unión Soviética. En 1963 se iniciaron en la URSS en la región de Krasnodar (Norte del Cáucaso), algunos experimentos de selección de carpas para lograr la resistencia a la hidropesía. Se han publicado los resultados de los 10 primeros años de trabajo. En este documento se describen los trabajos realizados durante 1973–75.

(*i*) En una granja experimental del Bajo Kuban se obtuvo en 1973–75 la quinta generación de carpas de la variedad Ropsha (R) y la tercera y cuarta generación de una carpa de tipo local muy extendida (Ls) y de híbridos de carpa Ucraniana-Ropsha (UR) y se procedió a su selección.

(*ii*) Se detectaron machos homozigóticos en el gene S (peces totalmente cubiertos de escamas) en la variedad UR (tercera generación), lo

que permite eliminar la segregación en esta variedad por la cubierta de escamas.

(*iii*) Prosiguió la selección de carpas según su tasa de crecimiento (en el primer año y, en parte, en el segundo) y su resistencia a la hidropesía (en el segundo y tercer año). El coeficiente de selección (i) por aumento de peso fue de 1,5–2,0. La selección por resistencia a la hidropesía fue más moderada.

(*iv*) Se realizaron experimentos sobre la infección de los peces (1+ y 2+) mediante inyecciones intraperitoneales de material patógeno procedente de la piel y las vísceras de peces enfermos. Durante los ensayos se estableció una dosis que resultó suficiente para inducir la enfermedad en un 50–80% de los peces inyectados.

(*v*) Las carpas Ropsha de dos años de edad de la cuarta generacion seleccionada son más resistentes a la hidropesía que los peces testigo no seleccionados de la misma variedad. La diferencia de resistencia, sin embargo, no es grande.

(*vi*) Las carpas de los tres tipos de híbridos ensayados (Ls × R, Ls × UR y R × UR) mostraron heterosis en su tasa de crecimiento y, en un caso (Ls × UR), en su viabilidad.

1 Introduction

Dropsy in the common carp (*Cyprinus carpio*) is a widespread disease which causes great damage to commercial carp farming in some countries of Eastern Europe and in the USSR. In the USSR, Ukrainian and particularly north Caucasian fish farms suffer great losses from dropsy. The presence of a permanent endemic centre of dropsy in the lower reaches of the Kuban river and the estuary of the Azov Sea makes it difficult to control this disease in pond fish farms of the Krasnodar region (north Caucasus).

In southern parts of the USSR, carp selection for increased resistance to dropsy acquires special significance. Experiments on such selection were started in the Krasnodar region in 1963, and the results of the first decade of these experiments mave been published (Kirpichnikov *et al*, 1967, 1971, 1975; Kirpichnikov and Faktorovich, 1969; and others). This paper contains information obtained over the period 1973–75.

2 Materials and methods

The experiments were carried out on an experimental plot in the Lower Kuban including seven ponds with a total area of 2·7 ha. Selection was conducted simultaneously in the following three breed groups of carp chosen after preliminary tests:

(*i*) The Ropsha scaly carp (R)—a breed derived in the Leningrad region by a group of selectionists headed by V. S. Kirpichnikov. The selection of hybrids between the Amur wild carp and Galician cultured carp formed the basis of this breed (Zonova and Kirpichnikov, 1971; Kirpichnikov, 1972).

(*ii*) The local 'scattered' or 'sparse-scaled' type of mirror carp (Ls)—a strain of mixed origin with an admixture of heredity of the Amur and, possibly, Kuban or Don river wild carps.

(*iii*) The Ukrainian-Ropsha hybrid scaly carp (UR)—a strain obtained through crossing the Ropsha carp with the Ukrainian 'frame-scaly' carp, a breed derived in the Ukraine under the guidance of selectionist A. I. Kuzema (Kuzema, 1971). The crossing of the Ropsha and Ukrainian carps in the first generation results in considerable heterosis (Kuzema and Tomilenko, 1962; Tomilenko and Alekseenko, 1970).

In addition to these three groups of carp, hybrids between them (Ls × R, Ls × UR and R × UR) were made annually in an experimental plot.

To reproduce selected carps, hypophyseal injections were given and the eggs fertilized artificially, followed by incubation in the Weiss apparatus. In experiments aimed at speeding up selection, two-year-old carp were grown 1·0–2·5 kg by the end of July and then transferred to ponds for natural spawning (Kirpichnikov and Shart, 1974).

The selected fish were reared from fry to spawners at a reduced stocking rate. Carp strains grown together were marked serially. The ponds were fertilized when necessary, and the fish fed an ordinary mixed food. The total yield of the ponds was 800–1 000 kg/ha/year.

Selection for weight was made mainly during the first year and partly during the second year of life. Two indices were used to determine the intensity of selection (Falconer, 1960; Kirpichnikov, 1971):

(*i*) $V = (n \times 100)/(N)\%$—the selection severity coefficient (where N = the number of fish before selection and n = the number of selected individuals)

(*ii*) $i = S/\sigma$—the coefficient of selection intensity (S = the selection differential and σ = the mean square deviation for weight).

Selection for resistance to dropsy was carried out during the second and third years. The contact method of infection, *ie*, addition of dropsy-infected carp to fish under selection, was applied in most cases. During the last few years, contact infection was supplemented by injection of a suspension from the skin and viscera of infected fish directly into the abdominal cavity of healthy specimens (Kirpichnikov, Factorovich and Suleimanjan, 1972).

In order to compare resistant and non-resistant fish, up to 250 carp fingerlings were weighed and measured each spring. Blood was taken *in vivo* from all specimens and at the same time they were individually marked. In fish which remained healthy after infection, the number of individuals was determined. This enabled comparison of two groups of fish (resistant and non-resistant) using all the characters studied before the onset of the disease.

3 Experimental results (1973–75)

3.1 *Reproduction of selected breed strains*

In 1973 and 1974, Ropsha carps (R) of the fifth selective generation as well as local (Ls) and Ukrainian-Ropsha hybrid (UR) carp of the third selective generation were cultivated. In 1975, the fourth generations of these two carp strains (Ls and UR) were first obtained. Mass crosses used in all these cases permitted reduction of the coefficient of inbreeding which is unavoidable when the number of spawners is small.

In growing different breeds of carp, the authors tried to obtain the following weight criteria:

	Age	*Weight(g)*
Fry of 25–30 days	—	2– 3
Fingerlings in autumn	0+	40– 60
Two-year-old fish	1+	600–1 000
Two-year-old fish (grown in spring (April–July) at a low stocking rate) before spawning	2	1 500–2 500
Three-year-old fish	2+	1 800–2 500

In 1974 these criteria could not be achieved owing to comparatively low summer water temperature and recessions in feeding. As a result, in the spring of 1975 fish of rather low weight were obtained. The state of their sexual products was however satisfactory. The existence of no less

than two generations in all strains (even three in strain UR) enabled us to obtain and grow simultaneously a few generations of carp which could be compared as to their degree of resistance to dropsy and by their growth rates. For this purpose, the second, third and fourth carp generations from the UR selected strain were grown in 1975.

3.2 *Progeny testing of spawners for homozygosity by gene S*

It is known that a complete scale cover in carp is revealed by the presence of a dominant gene, S. Carp with the mirror type of scale (scattered form) are homozygous by gene S (Kirpichnikov, 1937; Probst, 1953). The strain UR originates from the crossing of the Ukrainian 'frame' carp (also of genotype ss) and the Ropsha carp (SS) which was carried out in 1965. In the second, third and fourth hybrid generations, 'scattered' specimens were eliminated. The elimination of all scattered fingerlings in each generation gradually reduced their number in progeny from 25% in the second generation to 3·2–8·5% (two crossings) in the fourth. To purify strain UR completely of undesirable heterozygotes Ss, progeny testing of males of the third selective generation was performed in 1975. Using the ordinary backcrossing:

$$♂S\ (?) \times\ ♀ss$$

Out of 24 tested males, 14 (58·3%) were homozygous. Segregation was observed in the progeny from the ten remaining heterozygous males. Similar tests of females will permit obtaining a stock of spawners in the succeeding year completely homozygous with respect to gene S.

3.3 *Selection for growth rate*

Severity of selection for weight was moderate in all cases (Table I). The coefficient of selection intensity (i) of 1·5–2·0 may be assumed to be sufficient to prevent the decrease of growth indices due to inbreeding.

The values for V and i presented here were obtained mostly as a result of selection performed during the first year of life. Selection among two-year-old fish was allowed only before the onset of the disease, and, therefore, was less significant for the work.

TABLE I
SELECTION SEVERITY (V) AND SELECTION INTENSITY (i) FOR WEIGHT IN THREE STRAINS OF CARP

Strain	*Generation of selection*	*Year if birth*	V%	i
R (Ropsha)	5	1973	20·2	0·8
		1974	78·3	0·4
		1975[a]	33·5	2·2
Ls (Local 'scattered')	3	1973	7·1	1·9
		1974	15 6	0·7
UR (Ukrainian–Ropsha hybrid)	3	1972	15·6	1·5
		1973	15·6	1·6
	4	1975[a]	17·0	1·6

[a] Data for one-year-old fish only

3.4 *Improvement of infection technique in selection for resistance to dropsy*

Experiments on the infection of carps via intraperitoneal injections of pathogenic material were carried out repeatedly. In some cases the results were negative (Artjuch and Ostashevsky, 1954; Tetz, 1961). Other tests were more successful (Goncharov, 1946; Tomášec *et al*, 1964; Osadchaya, Prosjanaja and Ligotzkaja, 1970). In 1974 and 1975 a new series of experiments was carried out on infection in order to solve two problems:

(*i*) to define the dose of contagious matter which would ensure the infection of 50–80% of all inoculated fish, and

(*ii*) to undertake mass selection for resistance among carp of various breeds.

The first two experiments (Table II) show that the number of infected fish depends considerably on the dosage. For small (30–40 g) one-year-old carp 1 ml of filtered suspension would be sufficient, whereas large fish (over 500 g) must be injected with 5 ml of suspension. Such doses are relative since the concentration of the pathogenic agent in the suspension may vary widely.

In the course of the third and fourth experiments for further confirmation, fish which remained healthy after injection (Table II) were chosen. Experiment No. 4 with three-year-old fish was particularly successful; 17 specimens which were resistant to dropsy were selected (21·5% of the original number).

3.5 *Selection for resistance to dropsy and its efficiency*

During the past few years dropsy was not very pronounced

TABLE II
INFECTION OF CARP WITH DROPSY BY PERITONEAL INJECTION OF SUSPENSION FROM SKIN AND VISCERA OF SICK FISH

Experiment No.	*Date*	*Age (years) and mean weight (g) of recipient fish*	*Amount of suspension (ml)*	Initial No. of fish	Mortality in the course of the test		*Caught at the end of test*		
					No.	%	Total No.	Healthy specimens included	
								No.	%
1[a]	18/6/74–1/7/74	1 350	1·0	19	1	5·3	10	1	5·3
			1·5	19	4	21·1	8	0	0
			2·0	19	9	47·3	3	0	0
2[b]	31/5/75–19/6/75	1+ 32	Control	20	2	10·0	18	14	70·0
			0·5	20	10	50·0	10	8	40·0
			1·0	20	11	55·0	9	6	30·0
			1·5	10	7	70·0	3	0	0
3	22/6/75–27/6/75	1+ 186	1·0	60	0	0	60	36	60·0
	1/8/75						33	19	31·7
4	10/6/75–19/6/75	2+ 670	5·0	79	61	77·2	18	17	21·5

[a] The number of fish caught and dead fish are underestimated because (for technical reasons) not all fish in the experimental tank were caught
[b] Physiological solution (1 ml) was introduced peritoneally to all control fish. Four specimens had weak symptoms of chronic dropsy by the end of the experiment

in the nursery ponds, occurring among I+ fish mainly in the second half of summer. An outbreak of the disease occurs in the third year (Kirpichnikov *et al*, 1975). The losses and rejections of sick fish in the 1971–74 generations are summarized in Table III. It is clear that the selection was rather intense, from 2 to 23% of the initial number of stocked fish being kept for breeding. Deaths caused by non-dropsical agents are included in the number of dead and rejected fish since it was next to impossible to separate them from dropsy-induced lethal cases. The true severity coefficient of selection was likely to have been 30–40%.

Control carp brought from Ropsha in the summer of 1971 and used in the comparative test in 1972 proved to be less resistant to dropsy during the second year of life than selected Ropsha carp of the fourth generation (Kirpichnikov *et al*, 1975). By the third year these carp differed only slightly in their resistance to dropsy. With respect to their degree of resistance, two-year-old local carp (Ls-2 and Ls-3) and Ukrainian-Ropsha hybrid carp (UR-2 and UR-3) were inferior to Ropsha carp. The only exception was the experiment of 1973 when, at stocking, Ropsha carp were found to weigh less than 6 g. In three-year-old fish the relations were frequently inverse—Ropsha carp caught dropsy more often than other breeds of carp.

According to their weight indices, Ropsha control carp were slightly behind the selected ones; the autumn weights of the two groups were 529 g and 554 g respectively. This difference was not statistically significant. It may be said with certainty that selection for resistance to dropsy did not

TABLE III
SELECTION SEVERITY FOR RESISTANCE OF CARP TO DROPSY

Year of birth	*Breed and generation*	*Two-year-old fish*		*Three-year-old fish*		*Selection for breeding*	
		Initial No.	*Mortality and rejection %*	*Initial No.*	*Mortality and rejection %*	*No.*	*% of the initial No.*
			1972		1973		
1971	R-4	800	23·9	370	57 3	128	16·0
	Ls-2	489	38·2	172	37 0	84	17·2
	UR-2	700	36·5	236	41·9	114	16·3
			1973		1974		
1972	R-4	547	21 9	358	96 4	13	2·3
	Ls-3	426	40·4	256	87·0	35	8·2
	UR 3	1 025	44·2[a]	401	89·5	42	4·1
			1974		1975		
1973		826	51 5	289	30 8	88	10 7
	R-5			20[b]	80·0		
	Ls-3	535	38·2	164	54·5	41	7·6
	UR-3			20[b]	95·0		
		410	35 2	186	40·0	89	21·7
				20[b]	85·0		
			1975				
1974	R-5	21[b]	81·0	—	—	—	—
	Ls-3	19[b]	68·4	—	—	—	—

[a] The high mortality of UR-3 carp in 1973 was associated mainly with overheated water during stocking and not with dropsy
[b] The results of tests with individual infection

TABLE IV
GROWTH AND VIABILITY OF COMMERCIAL INTERSTRAIN HYBRIDS Ls × R, Ls × UR and R × UR

Year	*Breed and generation*	*Initial No. of fish*	*Mean weight at stocking (g)*	*Mean weight at time of fishing (g)*[a]		*Mortality %*
		One-year-old fish (O+)				
1973	UR-3	502	21·3	48·3	35·7	39·9
	Ls × UR	2 870	15·0	44·8	44·8	7·9
	Ls-3	174	18·5	45·4	38·4	6·9
1974	Ls 3	1 780	6·2	26·7	26·7	39·4
	Ls × UR	1 500	9·3	35·4	29·2	22 9
	R-5	930	5·9	32·2	32·2	41·4
1975	Ls-4	261	4 4	33·3	31·7	43·3
	R-5	1 000 25/6	3 6 25/6	42·7	42·7	33·7
	R × UR	1 000	4·9	76·2	73·6	17·6
	UR-4	1 200 1/8	3·8 1/8	16·2	—	16·4
		Two-year-old fish (1+)				
1973	Ls-3	426	49	560	560	40·4
	Ls × R	98	71	733	623	57·7
	R-4	547	63	616	545	21·9
1974	Ls-3	535	57	517	512	38·2
	Ls × UR	300	62	567	537	33·4
	UR-3	410	56	477	477	35·2
1975	Ls-3	500	30	569	569	17·4
	Ls × UR	300	35	563	538	15·2
	R-5	400	30	554	554	26·0

[a] Actual weight corrected. Correction coefficient was equalized to 2(0+) and 5(1+)

involve a decrease in carp growth (as the 'correlated response'), and that the effect of inbreeding was not essential.

3.6 *Commercial hybridization between various selected carp strains*

To estimate the breeding value of hybrids between selected strains in pond fish farms, it is necessary to test all possible hybrid combinations (Ls × R, LS × UR, R × UR and reciprocal crosses).

Increased growth of one-year-old hybrids Ls × R (local × Ropsha) was reported as early as 1972 (Kirpichnikov *et al*, 1975). This advantage was retained during the second year of the fish's life (in 1973). It was rather considerable even when corrections for difference in the initial weight (Wohlfarth and Moav, 1972) were introduced. The correction coefficient was assumed to be equal to 5. As regards survival rate, however, hybrids Ls × R had no advantages (Table IV).

Heterosis in viability and growth capacity was found in the interstrain combination Ls × UR in the course of the first two years of life. The accelerated growth of hybrid larvae and fry when compared with growth of the pure strains is unusual. Therefore, correction coefficients should be introduced when weight data are being treated. In one instance (in 1975) two-year-old hybrids Ls × UR were inferior to Ls carp in their weight gain. It is not unlikely that this is the result of selection of the largest Ls specimens during their stocking into ponds. The preference with respect to viability of Ls × UR hybrids is beyond doubt (Table IV).

Only one experiment was carried out in 1975 with R × UR intercrossing. Heterosis in growth rate of one-year-old fish was very large and their viability was also satisfactory (Table IV). New tests with fingerlings and two-year-old fish are planned. Hybrids of all reciprocal combinations should be tested in future.

3.7 *Morphophysiological and biochemical differences between resistant and non-resistant fish*

The experiments of 1971–73 show that two-year-old carp which remained healthy after a strong outbreak of dropsy, exhibit a higher weight, an improved condition factor and an increased haemoglobin content (Kirpichnikov *et al*, 1975). In the stock of resistant fish, the frequency of both the genotype FF of serum esterase locus and the genotype AB of transferrin locus were increased (Tsherbenok, 1973). The differences in weight and condition factor were statistically reliable.

4 Discussion

The small size of the experimental plot did not permit a retention of a sufficient number of spawners of the three selected carp strains. As a result, inbreeding in these strains was inevitable. In this situation, commercial interstrain crossings will be of great importance, and rearing of first-generation hybrids will eliminate the effect of inbreeding. A strongly pronounced heterosis evidenced by the growth rate in all combinations and by viability in the hybrids Ls × UR suggests great opportunities for commercial hybridization.

It is not yet clear how resistance to dropsy is inherited in carp. The resistance to epidermal epithelioma and to swim-bladder inflammation is dominant (Hines *et al*, 1974). Once the resistance to dropsy is also controlled by dominant genes, hybrids must be comparatively immune. If, on the contrary, resistance is the consequence of recessive gene storage, hybrids will be sensitive to infection. This problem must be solved as soon as possible.

Carps heterozygous by the genes S and s show advantages in growth capacity as compared to the homozygotes SS (Kirpichnikov, 1966). All offspring from the intercrossings Ls × R, Ls × UR and reciprocal combinations would be heterozygous (Ss) which would increase the advantage of interstrain hybrids.

There is still much uncertainty as regards the technique of dropsy infection. It is difficult to obtain a standard dose of the pathogenic material used for inoculation. The situation is complicated by the intricate etiology of dropsy. It is not known whether variation in the degree of acquired immunity in fish of different origin affects the results of infection. Finally, selection efficiency may be reduced in case of the presence of a few genetic types of the pathogenic agent.

The first attempt to determine the efficiency of the selection (for strain R) shows that it is rather small and the difference in the resistance occurs only in two-year-old carp. It may be associated with a small number of past selection generators. In actuality, only two generations undergo rather strong selection. It may be also a consequence of a relatively low heritability (h^2) of this trait.

It is very difficult to choose control material to determine selection response. In the opinion of the authors, the optimal approach is a simultaneous production of several selected carp generations. The presence of three subsequent generations of Ukrainian-Ropsha strain (UR-2, 3 and 4) of the same age in the experimental ponds will permit comparison of fish from these generations by the extent of their resistance to dropsy in future studies.

The search for differences between resistant and non-resistant fish as indicated by their morphological, physiological, biochemical and immunological characters, as well as by their blood groups, is of particular importance.

Analysis of these differences will be a first stage in the study of genetics of disease-resistance in carp.

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Crossbreeding Hungarian Races of Common Carp to Develop More Productive Hybrids

J. Bakos

Abstract

There are 22 000 ha of fish ponds in Hungary managed by the State. The fish produced on these farms are 80–85% common carp (*Cyprinus carpio*); other species produced include Chinese carps. Methods have been sought to improve production of common carp and decrease its cost. One way to achieve this purpose is to improve the productive capacity of carp through breeding, as is done in poultry and pig farming. Experiments along these lines have been carried out since 1962 at the Fish Culture Research Institute at Szarvas, Hungary, to capitalize on the effects of heterosis and crosses of inbred lines.

The Hungarian races of common carp have been bred two or three generations at Szarvas, and the more important characters which determine production value and their heritability subjected to performance tests. The following characteristics were considered: (*i*) egg fertility; (*ii*) survival to time of harvest (both first and second year); (*iii*) growth in weight during the second year; (*iv*) food conversion; (*v*) amount of consumable flesh; (*vi*) fat content.

Successful fertilization in inbred lines was 50–60%, in non-inbred lines 60–80%, in hybrids 80–95%. Survival until harvest of hybrids was 16% higher than in the pure races and in combined evaluation of both first and second year survival they showed 21% better viability. Hybrids had 15–40% better growth than the pure races. They used 15–30% less feed than pure lines and under intensive feeding had 2–5% less fat content.

Two-, three- and four-line hybrids were produced from different pure races. They showed heterosis effect and exceeded parental lines in many features. Egg fertility, growth and food conversion all improved as an effect of this crossbreeding and fat content decreased. On the basis of collective evaluation of several important characters, hybrids could be obtained that ensured an improvement of 15–20%.

The lines produced at the Institute are purchased by production farms which breed hybrid carps of high productive quality.

Croisement de races hongroises de carpe commune visant à obtenir des hybrides plus productifs

Résumé

Il existe en Hongrie 22 000 ha d'étangs de pisciculture gérés par l'Etat. Les poissons produits par ces exploitations piscicoles sont pour 80 à 85% des carpes communes (*Cyprinus carpio*); on y élève également des carpes chinoises. L'on s'est efforcé de trouver des méthodes permettant d'améliorer la production de la carpe commune et de abaisser le coût de production. L'un des moyens d'y parvenir est d'augmenter la capacité productive de la carpe par sélection, comme on le fait dans les exploitations de volailles et de porcins. Des expériences ont été menées depuis 1962 à l'Institut de recherche sur la pisciculture de Szarvas (Hongrie) dans le but de tirer parti des effets de l'hétérosis et des croisements de lignées consanguines.

On a élevé deux ou trois générations de races hongroises de carpe commune à Szarvas et l'on a soumis à des tests de performance les caractères qui déterminent leur valeur productive et leur héritabilité. Les caractéristiques ci-après ont été examinées: (*i*) fécondité des œufs; (*ii*) survie au moment de la récolte (tant à la première qu'à la deuxième année); (*iii*) croissance pondérale pendant la deuxième année; *iv*) conversion alimentaire; (*v*) quantité de chair consommable; (*vi*) teneur en graisse.

Le taux de fécondation était de 50 à 60% dans les lignées consanguines, de 60 à 80% dans les lignées non consanguines et de 80 à 95% chez les hybrides. La survie jusqu'au moment de la recolte des hybrides était de 16% plus élevée que dans les races pures et, lors d'une évaluation mixte de la survie à la première et à la deuxième année on a constaté une amélioration de 21% du taux de viabilité. Les hybrides avaient une croissance de 15% à 40% supérieure à celle des races pures, utilisaient de 15 à 30% d'aliments en moins que celles-ci et, dans des conditions d'alimentation intensives, leur teneur en graisse était de 2 à 5% moindre.

Des hybrides de deux, trois et quatre lignees ont été produits à partir de différentes races pures. Ils ont manifesté un effet d'hétérosis et nombre de leurs caractéristiques étaient supérieures à celles des lignées de geniteurs. A la suite de ce croisement, la fécondite des œufs, la croissance et les taux de conversion alimentaire ont tous été améliores et la teneur en graisse a été réduite. Sur la base de l'évaluation collective de plusieurs caractères importants, l'on pourrait obtenir des hybrides procurant une amélioration de 15 à 20%.

Les lignées produites à l'Institut sont acquises par des exploitations piscicoles qui élèvent des carpes hybrides d'une haute productivité

Cruzamientos de razas húngaras de carpa común para desarrollar híbridos más productivos

Extracto

En Hungría existen 22 000 hectáreas de estanques piscícolas administrados por el Estado. Del 80 al 85% de los peces producidos en esas granjas son carpa común (*Cyprinus carpio*), y también se cultivan carpas chinas. Se ha buscado la manera de mejorar la producción de la carpa común y disminuir sus costos. Una forma de lograr ese objetivo es mejorar la capacidad productiva de la carpa mediante mejora genética, como se hace en la cría de aves de corral y de cerdos. Con tal fin se vienen realizando experimentos desde 1962 en el Instituto de Investigaciones Piscícolas de Szarvas, Hungría, para aprovechar los efectos de la heterosis y los cruces de líneas endogámicas.

Se han reproducido diez razas hungaras de carpa común por dos o tres generaciones en Szarvas, y se han sometido a pruebas de rendimiento los caracteres más importantes para la producción y su heradabilidad. Se tuvieron en cuenta las siguientes características: (*i*) fertilidad del huevo; (*ii*) supervivencia hasta el momento de la recolección (primero y segundo año); (*iii*) aumento en peso durante el segundo año; (*iv*) conversión alimenticia; (*v*) cantidad de carne consumible; (*vi*) contenido en grasa.

La fertilización en líneas endogámicas tuvo éxito en un 50–60% de los casos, en líneas no endogámicas en un 60–80% y en los híbridos en 80–95%. La supervivencia hasta la recolección fue mayor en un 16% en los híbridos que en las razas puras y en la evaluación conjunta de la supervivencia en los dos primeros años, la viabilidad de los híbridos resultó mejor en un 21%. El crecimiento de los híbridos fue superior en 15–40% al de las razas puras. Estos consumieron de un 15% a un 30%

menos de alimentos que las líneas puras y con alimentación intensiva su contenido en grasa fue inferior en 2–5%.

Se produjeron híbridos de dos, tres y cuatro líneas a partir de razas puras distintas. Estos mostraron heterosis y superaron a las líneas de progenitores en muchas características. Como efecto de los cruzamientos, mejoraron la fertilidad del huevo, el crecimiento y la conversión de los alimentos, y disminuyó el contenido en grasa. Teniendo en cuenta colectivamente varias características importantes, ha sido posible obtener híbridos que permiten una mejora del 15–20%.

Las líneas producidas en el Instituto son compradas por granjas piscícolas que crían carpas híbridas de calidad altamente productiva.

1 Introduction

In Hungary, there are 22 000 ha of fish ponds on farms managed by the State. Of the fish produced at these fish farms, 80–85% are common carp (*Cyprinus carpio*) and 10–15% are Chinese herbivorous carps and other species. In order to increase the quality and quantity of common carp production, a search has been made for new methods which do not involve much expense and afford a possibility not only for further increase in production but also for a decrease in the costs of production.

In the course of research on carp selection at the Fish Culture Research Institute at Szarvas, begun in 1962, it was decided that rapid improvement in the production capacity of carp, like that of poultry and pigs, could be attained by employing breeding methods that successfully utilize the effects of inbreeding and heterosis resulting from crosses of inbred lines.

2 Methods

Ten Hungarian races ('land races') of common carp were used for genetic crosses. These 'land races', collected from different fish farms, have been bred through two or three generations at Szarvas. The more important characters determining the individual production value of selected males and females and their inheritability were subjected to comparative performance tests. (See Fig. 1 for a scheme of the breeding work.)

In making each cross, only one male and one female were used in artificial fertilization. During the first year the brood groups were nursed in separate ponds; in the second year they were nursed in a common pond.

The breeding carp were identified by burns or brands. The line number of the female and male and the individual number of the fish were burned on by an electric branding instrument. The progeny populations were differentiated by collective marks, each group receiving a branded stripe, 2 cm long, on different parts of their bodies. Marks made by this method are visible for two to three years.

In planning crossing combinations the following aspects were taken into consideration: (*i*) mating outstanding females and males possessing the same value for stabilization and further improvement of advantageous characters; (*ii*) mating of a male and female which were outstanding in two different characters for a combination of advantageous features; (*iii*) mating of one female with outstanding characters and more males for the control of combination ability and for the selection of the most suitable lines of males; and, (*iv*) mating of related individuals within pure lines for the production of inbred lines.

The production capacity of carp hybrids was established by the evaluation of the following characters: (*a*) egg fertility, (*b*) percentage of survival to first and second year harvest, (*c*) increase in weight during the second year, (*d*) food conversion ability, (*e*) percentage of consumable flesh, and (*f*) fat content of flesh.

Eight to twelve hybrid combination lines were evaluated yearly and 200–300 marked individuals from each population were stocked in a common pond. The data were obtained by measuring all the fish individually, and their authenticity controlled by variance analysis. In the case of artificial propagation, egg fertilization was checked by samples taken from hatching jars.

3 Results

Egg fertility is an important index of the viability of the

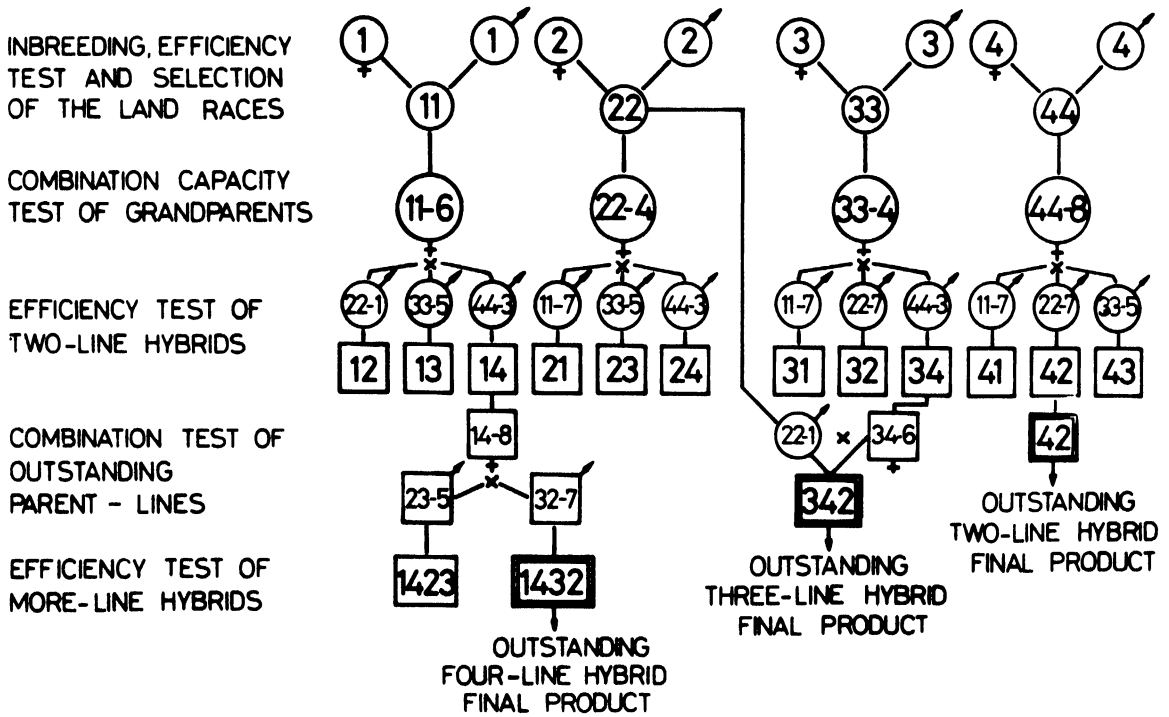


Fig 1. Scheme of production of common carp hybrids, showing the processes of breeding work

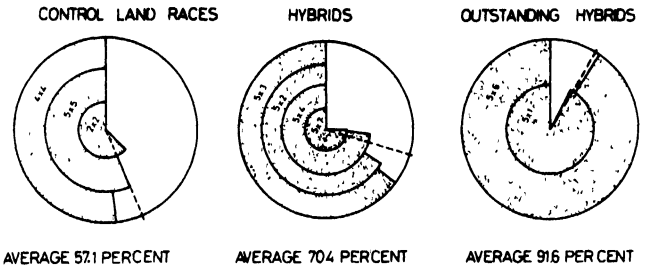


Fig 2. Comparison of egg fertility in pure land races and hybrids of common carp

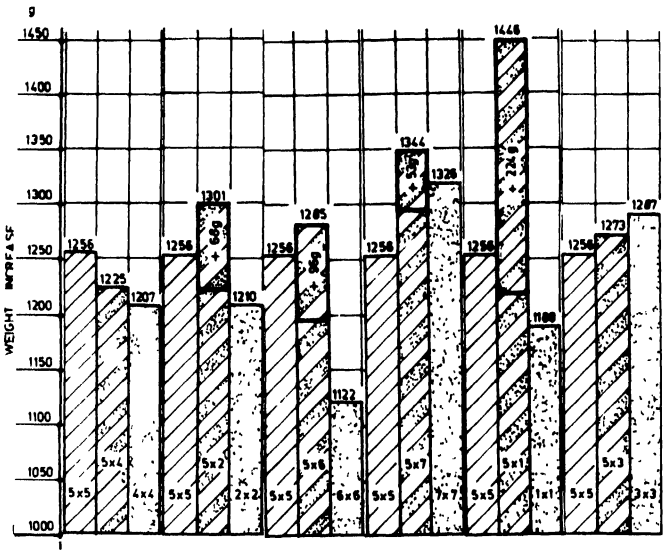


Fig 3. Heterosis effect in the weight increase of the hybrid carp

hybrids. Successful fertilization of the inbred lines was 50–60%, that of non-inbred lines was 60–80%, and that of hybrids was 80–95%—in some cases even better.

The number of individuals surviving to harvest as compared with the number stocked is another important and measurable index of the viability of carp. The percentage of harvestable hybrids was always higher every year than that of pure land races. As an average of a few years, the best hybrids gave a 16% higher harvesting survival. One three line hybrid had a 99% survival from 30 days of age until 180 days. In evaluation of both first and second year survival the hybrids exhibited 22% better viability.

Comparison of pure land races and hybrids reared in the same pond showed that under favourable conditions the hybrids had 15–40% better growth.

The carp were fed with wheat and other cereals. It was necessary to supply 2·8–3·5 kg of feed to produce 1 kg of fish flesh. The hybrids used 15–30% less feed than the pure lines.

During the selection trials, attention was paid to improvement of the quality of flesh and to decrease in percentage of fat. Under intensive feeding, the fat content of carp flesh was 12–20%. The hybrids had flesh with 2–5% less fat content.

During these carp hybridization experiments, two-, three- and four-line hybrids were produced by the crossing combination of different genotype land races of carp. The hybrids showed heterosis effect in their qualitative and quantitative features and exceeded the parental lines in many important features.

As an effect of this crossbreeding, egg fertility improved (over an average of a few years) more than 16% over that of the land races (Fig. 2). The heterosis effect which appeared in the growth resulted in 20·1% increase in growth in the best combinations of hybrids over an average of ten years of experiments (Fig. 3). The hybrids used 14·5% less feed to increase 1 kg in weight.

High fat content in carp bred in European fish farms can be decreased by 2–5% by crossing well chosen breeders.

On the basis of a collective evaluation of several important characters, it was established that by crossbreeding different land races of carp, hybrids could be obtained that ensured an improvement of 15–20% in intensive fish farming with minimum financial expenses.

The lines of parents and grandparents established by this inbreeding and selection programme are produced in Hungary only within the genetic programme of the Fish Culture Research Institute. More than 10 000 females and males are bred here. They are then purchased by production farms that breed hybrid carps of high production capacity obtained by crossbreeding these fish.

A Proposal for the Continuous Production of F_1 Hybrids Between the European and Chinese Races of the Common Carp in Traditional Fish Farms of Southeast Asia

R. Moav, T. Brody, G. Wohlfarth and G. Hulata

Abstract

The Chinese race of the common carp (*Cyprinus carpio*), known as the big-belly carp, is a very hardy fish and well adapted to the harsh environment of the traditional carp ponds of southeast Asia. However, it has a set of economically negative characteristics: slow growth rate, high fecundity, early sexual maturity, and a well developed capacity to escape fishermen's nets. These multiple faults can be genetically corrected by substituting the big-belly carp with its F_1 hybrid with the European domesticated carp. Introduction of European carp spawners of a single sex, say females, into undrainable ponds populated with big-belly carp would create a system for the *in situ* continuous production of heterotic inter-race hybrids. The dynamics of the system may be analysed experimentally using electrophoretic genetic markers having different alleles in the two races.

Proposition visant à la production en continu d'hybrides F_1 entre races européenne et chinoise des carpes communes dans les stations piscicoles traditionnelles de l'Asie du Sud-Est

Résumé

La race chinoise de carpe commune (*Cyprinus carpio*), est extrêmement résistante et bien adaptée au milieu hostile que constituent les étangs à carpes traditionnels de l'Asie du Sud-Est. Cependant on constate une série de caractéristiques négatives du point de vue économique: lenteur de la croissance, fécondité importante, maturation sexuelle précoce et capacité très développée d'échapper aux filets des pêcheurs. Ces défauts peuvent être corrigés par manipulation génétique en remplaçant la carpe chinoise par son hybride F_1 obtenu avec la carpe domestique européenne. L'introduction de carpes reproductrices européennes, des femelles par exemple, dans des étangs non vidangeables peuplés de carpes

chinoises, créerait un système adapté à la production continue *in situ* des hybrides hétérogènes interraciaux. La dynamique du système peut être analysée expérimentalement en utilisant des marqueurs génétiques électrophorétiques qui présentent des allèles différents dans les deux races.

Propuesta para la producción continua de híbridos F_1 de las razas europea y china de carpa común en explotaciones piscícolas tradicionales del Sudeste de Asia

Extracto

La raza china de carpa común (*Cyprinus carpio*) conocida como carpa de vientre hinchado es un pez muy resistente y perfectamente adaptado al difícil ambiente de los estanques tradicionales de carpas del Sudeste de Asia. Sin embargo, tiene varias características negativas desde el punto de vista económico: crecimiento lento, elevada fecundidad, madurez sexual temprana, y gran capacidad de eludir las redes de los pescadores. Estos múltiples defectos pueden corregirse genéticamente sustituyendo ese tipo de carpa con su híbrido F_1 obtenido con el cruce con carpas domésticas europeas. La introducción de reproductores de carpa europea de un solo sexo, por ejemplo hembras, en estanques sin drenaje poblados con carpa de vientre hinchado permitiría crear un sistema para la producción continua *in situ* de híbridos interraciales heteróticos. La dinámica del sistema puede analizarse experimentalmente utilizando marcadores genéticos electroforéticos con diversos alelos en las dos razas.

1 Introduction

1.1 *Big-belly carp of China*

Big-belly is the common name of the major race of carp (*Cyprinus carpio*) found in China and the neighbouring countries of southeast Asia (Drews, 1961). It has been grown and reproduced for over 2 000 years on Chinese farms whose major husbandry features (polyculture, high stocking rates and manure feeding) interact to create a very harsh environment. Under these conditions, the big-belly carp has had to survive and adapt.

These changes were not always in the best interest of the fish farmer (Wohlfarth, Moav and Hulata, 1975). In order to survive in the ponds, the big-belly carp developed, through many generations of evolution, a high degree of resistance to the elements of its environment. The adaptations include fast post-hatching growth rate, high fecundity, and early sexual maturity. In order to evade its greatest predator, the fisherman, the big-belly carp acquired an amazing capacity to escape the fishermen's nets, very slow growth rate after the onset of gonad maturation (at about the age of three months) and prolific reproductive capacity even at sizes smaller than acceptable market weight (Moav, Hulata and Wohlfarth, 1975; Wohlfarth, Moav and Hulata, 1975; and Wohlfarth *et al*, 1975). During the long period of its domestication, the big-belly carp had not, it seems, been subjected to artificial selection for fast growth rate. All these characteristics, namely slow growth rate, seine escapability and early sexual maturation have strong negative economic values and their genetic 'correction' would offer an enormous benefit since the big-belly carp is cultured in ponds covering hundreds of thousands of hectares.

1.2 *Domesticated European carp*

A natural candidate for correcting the faults of the big-belly through crossbreeding is the domesticated European carp. This race of carp has had quite a different evolutionary history from that of its Chinese relative. It was cultured at low stocking densities, received regular grain feeding, protected against predators and diseases and was harvested by emptying the ponds rather than by seining. Also, the reproduction of the European domesticated breeds was under the control of the breeders who applied a continuous, strong selection for fast growth rate over many generations. These circumstances gave rise to a fast-growing, late-maturing carp, which is caught easily by the fishermen's nets (low seine escapability). On the negative side, it is poorly adapted for survival in harsh environments, such as

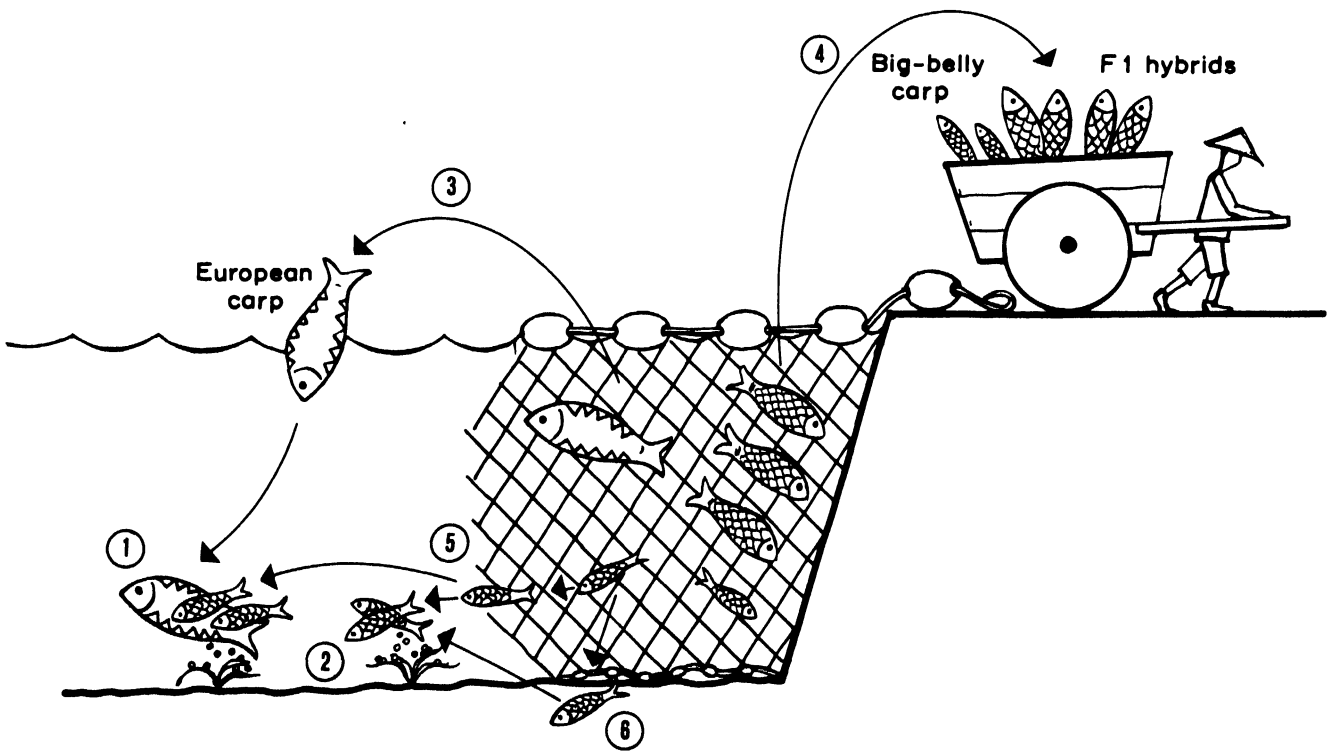


Fig 1. Illustration of the perpetual production of F_1 hybrids between the European and the Chinese (big-belly) carps in undrainable ponds. (1) Large European carp females spawn with small big-belly carp males; (2) Big-belly carp spawn together; (3) Captured European carp females (mirror scale pattern) are thrown back into the pond; (4) Captured scaly carp, mostly F_1 hybrids and some big-belly carp, are hauled to the market; (5) Small big-belly carp escape through the meshes of the seine net; (6) Big-belly carp evade the seine by hiding in the mud

those common in the traditional carp ponds of China, which rules out its direct substitution for the big-belly carp.

1.3 *European × Chinese carp hybrids*

Extensive tests conducted at the Fish and Aquaculture Research Station at Dor (Israel) proved the overwhelming superiority of the F_1 hybrid in comparison with the parental European and Chinese races of carp under conditions simulating those of traditional carp farming in China. This hybrid inherits the positive qualities of its European parents while maintaining the hardiness of the Chinese parent, a combination which results in a strong heterosis of overall economic value (Moav, Hulata and Wohlfarth, 1975; Hulata, Moav and Wohlfarth, 1976).

1.4 *Problems associated with introduction of F_1 hybrids to traditional ponds*

Production of F_1 hybrids requires separate maintenance of parental stocks. The European carp may be maintained and further improved by a central breeding station that could supply selected breeding stocks to many farms covering thousands of hectares of ponds. Farms that maintain drainable reproduction ponds for the breeding of crossbreds need only acquire selected European carp parents of a single sex, either male or female, that would be spawned with the endogenous big belly carp of the opposite sex to produce 100% F_1 fry for stocking the production ponds.

On traditional farms, where the ponds which already produce pure-bred Chinese carp are undrainable, production and growth of F_1 hybrids becomes more complicated. The traditional farmer does not want to be dependent on an annual supply of expensive seed stocks. He is willing to invest initially in high-quality reproductive material if he can raise his own for subsequent generations. This would be difficult if heterosis of the first hybrid generation (F_1) has to be maintained, however, unless some scheme can be devised for the annual automatic reproduction of F_1 hybrids on each small farm without restocking.

This paper deals with the most difficult ponds, *ie*, ponds that cannot be drained at will. Here the situation is further complicated by the inability to remove the endemic fish population. A simple scheme is, therefore, described that would hopefully ensure a continuous production of a high proportion of Chinese × European F_1 carp hybrids even in these undrainable ponds.

2 Continuous production of European × Chinese carp hybrids in undrainable ponds

The proposal for production of hybrids in traditional ponds requires the introduction of relatively large European carp spawners of a single sex (say female) into the pond, in addition to the endogenous pure Chinese carp breed. It is considered that in such mixed ponds, frequent harvesting by seining plus the biological differences between the endogenous big-belly carp, the European carp and their F_1 hybrids would ensure a continuous production and harvesting of a high proportion of F_1 hybrids. This 'steady state' situation is illustrated in Fig. 1.

The large European female carp are easily distinguished from big-belly carp by their mirror scale pattern (a frame consisting of a small number of scales on an otherwise naked skin). They should also be brand-marked conspicuously (Moav, Wohlfarth and Lahman, 1960). The mirror scale pattern is controlled by a single gene locus, and it is recessive to the wild-type full-scale cover of the big-belly carp. The large European carp females mate with big-belly carp males to produce abundant F_1 fry (item 1, Fig. 1). The big-belly carp males also mate with big-belly carp females (item 2) producing a new generation of pure big-belly carp fry. Thus, the pond has three distinct groups of carp: the endogenous, scaly big-belly carp; the F_1 hybrids which are also scaly; and a relatively small number (say two or three per hectare) of large mirror scale pattern European carp females. Each time the farmer casts his nets for harvesting, he catches European carp females because they have only a limited capacity to escape seines. These European carp females are easily distinguished by their distinct morphology and should be thrown back into the pond (item 3, Fig. 1). At the same time, all the captured scaly carp are harvested (item 4, Fig. 1). They are composed of pure-bred big-belly carp and F_1 hybrids. But, due to their much lower capacity to escape the seines (items 5 and 6, Fig. 1) the proportion of captured hybrids should be around five times higher than that of the pure-bred big-belly carp (Wohlfarth *et al*, 1978). The escaping big-belly carp continue to reproduce (items 1 and 2, Fig. 1) thereby closing the cycle.

2.1 *Population dynamics*

An adequate fishing effort should ensure removal of the great majority of sexually mature F_1 hybrids. This is due to their higher relative catchability and considerably larger size. The big-belly carp population would also be continuously regulated by the removal of its biggest members. This would regulate their number and maximum size attained. Also, since the presence of fast-growing hybrid carp reduces the pressure to catch the big-belly carp, their size will be greater by the time they are harvested.

The scheme is obviously imperfect since some proportion of the harvest will consist of the slow-growing pure-bred big-belly carp, and some of the hybrids would reproduce prior to their removal from the pond. Once F_1 individuals participate in reproduction, three new populations of hybrid derivatives are added to the pond: F_2 hybrid generation; offspring of a backcross to the big-belly carp (BC_B); and offspring of a backcross to the European carp (BC_F). These three groups are expected to have higher economic value than the pure-bred big-belly carp although they lose half of the heterosis of the F_1 generation. The BC_F cross would have a relatively low juvenile viability and the survivors would be caught readily by the seines. Therefore, introgression in the direction of the European carp genotype is most likely a dead end. Similarly, high juvenile mortality and continuous harvesting by seining would strongly select against European carp genes in both the F_2 and BC_B generations. This process, if continued for several generations would result in the introgression of a highly selected group of European carp genes into the big-belly carp population, resulting in a new and genetically-improved breed.

2.2 *Monitoring the genetic changes*

Experimental evaluation of the present scheme requires monitoring the pond's population for several years to determine the proportions of pure Chinese carp breed, F_1's and subsequent hybrid generations both in the harvested and the reproducing populations. Segregation or mirror scale pattern in the F_2 and BC_F generations may supply proof for

reproduction of F_1 individuals and rough indications of their proportions in the pond. For more refined monitoring, electrophoretic genetic markers may be used. Two marker loci, each with different alleles in the Chinese and European carps, are sufficient for following the population changes for two hybrid generations.

In the Genetic Markers Laboratory of the Hebrew University, Jerusalem, Israel more than six electrophoretic markers have been found with different alleles in their European carp breeds and in the big-belly carp strain that was introduced in Israel from Taiwan Province of China in 1970 (Moav, Hulata and Wohlfarth, 1975). At least three of these markers (transferrins, MDH, and esterase) have a sufficiently simple genetic control to permit their use in the above analysis. In the transferrins and in one of the esterase loci in particular, alleles are present which are breed-specific and which can be used as positive markers for the various populations existing in ponds that have been altered for crossbred production.

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